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CONTENTS

Fallout from nuclear weapons tests...
May 5 - 8, 1959.
volume 1

FALLOUT FROM NUCLEAR WEAPONS TESTS

HEARINGS

BEFORE THE

SPECIAL SUBCOMMITTEE ON RADIATION

OF THE

JOINT COMMITTEE ON ATOMIC ENERGY

CONGRESS OF THE UNITED STATES

EIGHTY-SIXTH CONGRESS

FIRST SESSION

ON

FALLOUT FROM NUCLEAR WEAPONS TESTS

MAY 5, 6, 7, AND 8, 1959

VOLUME 1

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NOTE

This is volume 1 of the public hearings held May 5–8, 1959, on fallout from nuclear weapons tests. It covers a general review of developments since the 1957 hearings; a summary of new data on atmospheric fallout; and global fallout. Volume 2, starting with a summary of new data on uptake in milk, food, and human bone, covers fallout mechanisms, uptake; development in radiation biology; discussion of permissible exposure levels, status and implications of testing; discussion of surveillance; and summary of problems and needs, including level of support. Volume 3 is an appendix to the hearings containing additional materials pertinent to discussions. These materials cover supplemental statements on general aspects of fallout problem; the "Hot Spot" problem and strontium 90 in foods; AEC quarterly reports; comments on General Advisory Committee report; maximum permissible levels; biological effects; carbon 14; report of the United Nations Scientific Committee on the effects of atomic radiation—1958; nuclear detonations and meteorological aspects; classification and declassification; fallout research and organization; and bibliography. It is planned at a later date to publish a detailed index of the hearings. The index would appear as volume 4.

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FALLOUT FROM NUCLEAR WEAPONS TESTS

TUESDAY, MAY 5, 1959

CONGRESS OF THE UNITED STATES,
SPECIAL SUBCOMMITTEE ON RADIATION,
JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D.C.

The subcommittee met, pursuant to notice, at 10 a.m., in room P–63, the Capitol, Hon. Chet Holifield (chairman of the subcommittee) presiding.

Present: Representatives Holifield, Price, Durham, Aspinall, Van Zandt, Bates, and Westland; Senators Pastore, Jackson, Aiken, and Bennett.

Also present: James T. Ramey, executive director; G. Edwin Brown, Jr., and George F. Murphy, professional staff members; and Richard T. Lunger, technical adviser, Joint Committee on Atomic Energy.

Representative HOLIFIELD. The committee will be in order.

This is the first day of public hearings by the Special Subcommittee on Radiation on fallout from nuclear weapons tests. As many of you may remember, the subcommttee held extensive hearings on this subject in June 1957 and compiled some 2,000 pages of expert testimony. A summary analysis of this testimony was prepared outlining the key points emerging from the hearings, together with the major unresolved questions.

Today we are again meeting—some 2 years later—for the purpose of bringing the committee and the Congress up to date on developments which have occurred during this interim period. Second, public concern has risen sharply in recent months over the possible hazards of fallout from nuclear weapons tests. This public concern has coincided with the disclosure of new data on fallout and its distribution, which have served to highlight some of the key questions which were brought up in the subcommittee's 1957 hearings.

Other important questions have also arisen in this interim period which were not discussed in detail in the 1957 hearings. These include the problem of local hotspot areas, such as those which have occurred in Minnesota and North Dakota, and evidence of direct intake by animals and humans of fallout from the leaves of plants.

We will also be considering such questions as the recent revisions of standards relating to the so-called permissible levels of exposure by the National Committee on Radiation Protection and Measurements (NCRP), and by the International Commission on Radiological Protection (ICRP). Questions have been raised in recent weeks regarding the consistency of the recommendations by these groups with regard to exposure of the population to fallout, including strontium 90 and cesium 137.

Testimony will also be heard on the effects, from the standpoint of fallout, of alternative types of testing, including underwater, underground, atmospheric, and stratospheric testing. I would like to make clear that the present series of hearings will be limited to discussions on fallout from nuclear tests, not the implications of an all-out war. The subcommittee intends to take up this later subject separately in public hearings beginning June 1.

Finally, we will receive testimony at the present hearings on what is being done by the various Federal agencies and their contractors in the field of research on fallout. This has been a matter of considerable public discussion in recent months and I think it is important we develop information at these hearings on who is doing this work and how well the work is being directed or coordinated.

It is our objective at these hearings to get the facts on the record, insofar as those facts exist, and to receive the considered judgment of experts in areas where these facts are not available. Our hearings in 1957 left many important questions unanswered, and I hope that during the course of testimony this week we may at least gain new insight into some of them.

We have tried in the present hearings, as we did in 1957, to invite expert witnesses representing varying points of view, both as to technical background of the fallout problem and organizational interest. We believe that this is the fair way and the best way of having a balanced presentation for the guidance both of the Congress and the public at large.

We have also requested a number of statements for the record, and are inserting a bibliography. It is our hope therefore, that the record of the hearings will in every respect bring the 1957 hearings up to date.

Before we proceed, I would like to ask all of our witneses to express themselves as much as possible in layman's terms so that committee members and the public may gain a better understanding of the subject matter under discussion. I appreciate that much of the data to be discussed is highly technical in nature and I hope that the printed record will be complete as far as technical detail is concerned. At the same time I hope that our discussions will not get so bogged down in technical detail that the important policy implications to be considered will be submerged in the process.

At this point I would like to put into the record the subcommittee's announcements and outlines for these hearings.

(The documents referred to follow:)

FROM THE OFFICE OF THE JOINT COMMITTEE ON ATOMIC ENERGY

(No. 223—For release April 30, 1959)

Representative Chet Holifield, chairman of the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, today released the schedule for public hearings by the subcommittee, beginning Tuesday, May 5, on fallout from nuclear weapons tests.

The schedule includes the subject areas to be covered during the 4 days of hearings next week, together with a listing of the expert witnesses who are scheduled to testify on each subject.

As noted in the Joint Committee's release of April 26, 1959, these hearings are designed primarily to bring the committee and the Congress up to date on developments since the last fallout hearings in 1957.

They are also designed to cover new data and problems. These include the problem of local "hot spot" areas such as those affecting wheat in Minnesota; the question of nonuniformity of stratospheric fallout, and evidence of direct intake of fallout from leaves to animals and humans.

The hearings will be held in room P–63 (Old Supreme Court Chamber) of the Capitol, May 5–8.

Scope and Purpose of Fallout Hearings (Functional Outline)

GENERAL

The purpose of the new hearings will differ from that of the 1957 hearings. The new hearings will not attempt to cover the broad background information covered in 1957. Rather, the emphasis will be twofold:

(1) To update the 1957 hearings by covering the important developments concerning the distribution and uptake of fallout and concerning the biological effects of radiation, with particular reference to the "key points" and "major unresolved questions" set forth in the Joint Committee's Summary-Analysis of the committee's 1957 hearings (pp. 2, 3, and 4—copy attached).

(2) To dig more deeply and more clearly into specific topical points of interest and relevance to current fallout problems, and scientific and policy questions. Thus, for example, the current problem of "hot spot" areas, the role of direct uptake of fallout from leaf surfaces, and the problem of carbon 14, should be considered.

The emphasis this time, therefore, will be to cover and communicate a much fewer number of points more effectively. All this does not mean that no one will have to stop and define "curie" again, but this sort of thing will be a natural part of the discussion on topical points rather than a point in itself.

SUBJECT MATTER

I. Basic distinctions and their importance in a discussion of the fallout situation.

(*a*) Local versus worldwide fallout—difficulty of precise distinction, contrast in types of problems involved and in programs and administration to cope with each type.

(*b*) Monitoring surveillance versus research—a distinction in goals or purpose rather than in actual activity; problems of public understanding caused by confusing the two.

(*c*) Population versus individual risk; and controlled versus uncontrolled risk—the relationship of the type of risk to the type of protection standard applicable and to the type of policy decision being considered.

(*d*) Variability of fallout distribution (on the ground)—global, regional, and local. Relationships to different types of models.

II. How have worldwide fallout levels and their distribution changed since 1957? Consider levels in the atmosphere, and biosphere, up to and including human body burdens or external exposure. Consider new topics such as C^{14}. Compare Sr^{90} and Cs^{137}.

III. What are the developments since 1957 in our understanding of basic worldwide fallout mechanisms? What are the main sources of uncertainty and how can these be attacked and how are they being attacked?

IV. What types of forecasts of future worldwide fallout levels can be made and what types are useful? What is the basis of such forecasting? What are the forecasts?

V. What are the developments since 1957 in our understanding of the biological effects of radiation? Discuss genetic and pathologic effects. Emphasize statistical nature of findings.

VI. What is a rational basis for estimating and forecasting the hazard to man of worldwide radioactive fallout? How can such estimates be used? How should they relate to Government decision and policy problems?

VII. What is the basic nature and purpose of existing radiation protection standards? What is their applicability to the worldwide fallout situation? How do and should they relate to Government decision and policy problems?

VIII. As an example of the workings of the complex relationships involving scientific data, radiation protection standards, hazard evaluation, and policy, discuss the problem of so-called hot spots, how they arise, how they are discovered, what they imply scientifically, and what can and should be done about such problems.

IX. How is and how should the Government be organized to deal with the general problem of environmental contamination from worldwide radioactive fallout? At what levels in Government, or by what agencies, are and should policy, budget, and research—program decisions be made? How are potentially hazardous situations dealt with? How are problems of public understanding handled? What about the relationships between AEC and PHS, FDA, DOD, OCDM, ICRP, NCRP, and the UN Committee, etc.? What about relationships with State and local governments and with private groups?

X. How are data collected and reported in the worldwide fallout program? What is the present and future scope and direction of the research and monitoring—surveillance programs in the Government?

JOINT COMMITTEE ON ATOMIC ENERGY

SPECIAL SUBCOMMITTEE ON RADIATION

April 30, 1959

PUBLIC HEARINGS ON FALLOUT FROM NUCLEAR WEAPONS TESTS

May 5–8, 1959

SCHEDULE

Tuesday, May 5

Morning session, 10 a.m.: Opening remarks by Chairman Holifield (10 minutes).

I. Introduction.

A. General Review of Developments Since 1957 Hearings (75 minutes):

1. General introduction covering distinctions between local, tropospheric and stratospheric fallout; distinctions as to mechanisms of uptake; somatic and genetic effects; permissible doses; and predictions as to future effects of fallout from continued testing.

2. Discussion of current "hot spot" area problem, showing how explanation of problem involves consideration of several alternative hypotheses which will be taken up in greater detail in the course of the hearings.

Presentation by Dr. C. L. Dunham, Chief, Biology and Medicine Division, AEC.

B. Comment by public Health Service (45 minutes): Dr. Francis J. Weber, Chief, Division of Radiological Health, Public Health Service.

Afternoon session, 2 p.m.

II. Summary of new data on atmospheric fallout (gummed film, rainpots, soil, air, etc.).

A. Presentations:

1. Mr. Joshua Holland, Division of Biology and Medicine, AEC (20 minutes).

2. Dr. Frank Shelton, Technical Director, Armed Forces Special Weapons Project (20 minutes).

III. Global fallout: Mechanisms for determining: Statements to update theories and models of fallout patterns, uniformity vs. nonuniformity, banding, etc.

A. Presentations:

1. Dr. Lester Machta, U.S. Weather Bureau (40 minutes).

2. Dr. E. A. Martell, Cambridge Research Center, U.S. Air Force (20 minutes).

3. Dr. W. F. Libby, Atomic Energy Commission (20 minutes).

4. Dr. Frank Shelton, Technical Director, Armed Forces Special Weapons Project (10 minutes).

Wednesday, May 6

Morning session, 10 a.m.

B. Roundtable on global fallout (1 hour). Participants:
Dr. Wright Langham.
Dr. Lester Machta.
Dr. E. A. Martell.
Dr. Willard F. Libby.
Mr. Merril Eisenbud.
Mr. Hal Hollister.
Mr. Joshua Holland.
Dr. Frank Shelton.

IV. Summary of new data on uptake in milk, food, human bone (1 hour).
A. Dr. Conrad Straub, Taft Sanitary Engineering Center, Public Health Service, Cincinnati.
B. Dr. Wright Langham, Los Alamos Scientific Laboratory.

Afternoon session, 2 p.m.

V. Fallout mechanisms, uptake.
A. Soils, plants, and foliar deposition: Dr. Robert Reitemeier, AEC and Agricultural Research Service, Beltsville, Md. (30 minutes).
B. Animals, persons, discrimination, etc.: Dr. C. L. Comar, Cornell University (30 minutes).
C. Roundtable on fallout mechanisms and uptake in plants, soils, animals, and people. Participants:
Dr. Wright Langham.
Dr. William Neuman.
Dr. C. L. Comar.
Dr. Robert Reitemeier.
Dr. Arthur Wolf.
Dr. Harry A. Claypool.

Thursday, May 7

Morning session, 10 a.m.

VI. Developments in radiation biology (2 hours).
A. Somatic effects:
1. Dr. Austin Brues, Argonne National Laboratory.
2. Dr. Lloyd W. Law, National Cancer Institute, Public Health Service.
B. Genetic effects:
1. Dr. James Crow, University of Wisconsin.
2. Dr. W. L. Russell, Oak Ridge National Laboratory.

Afternoon session, 2 p.m.

VII. Discussion of permissible exposure levels.
A. Presentation (30 minutes):
Dr. G. Failla, Columbia University.
Dr. James Crow, University of Wisconsin.
B. Roundtable on permissible exposure. Levels in relation to weapons testing (30 minutes). Participants:
Dr. G. Failla.
Dr. James Crow.
Dr. Clinton Powell.
Dr. K. Z. Morgan.
Dr. Forrest Western.
Dr. Jack Schubert.
Dr. Lauriston Taylor.

VIII. Status and implication of testing.
A. Presentation (30 minutes) Dr. William Neuman.
B. Roundtable discussion (30 minutes). Participants:
Dr. William Neuman.
Dr. Wright Langham.
Dr. Willard F. Libby.
Mr. Joshua Holland.
Dr. Frank Shelton.
Dr. Lester Machta.
Mr. Hal Hollister.
Mr. Merril Eisenbud.
Dr. Walter Selove.
Dr. James Terrill.

Friday, May 8

Morning session, 10 a.m.

IX. *Discussion of surveillance, monitoring and research programs, and organization* (to include description and analysis of nature, scope, and extent, financing and organization, of fallout activities in their entirety being carried out by Government and private agencies).

A. AEC activities: Dr. Charles Dunham, Chief, Division of Biology and Medicine, AEC.

B. Public Health Service activities: Dr. Francis J. Weber, Chief, Division of Radiological Health, Public Health Service.

C. Defense Department activities: Hon. Herbert B. Loper, Assistant to the Secretary of Defense for Atomic Energy.

X. *Summary of problems and needs, including level of support.*

Representative HOLIFIELD. I would also like to express our appreciation to our informal steering committee for the hearings, and to AEC, the Public Health Service, the Defense Department, and others for their assistance in organizing these hearings.

Our first witness this morning will be Dr. Charles L. Dunham, Chief of the AEC Division of Biology and Medicine. Dr. Dunham, it is good to have you with us again this morning as our leadoff witness. I understand that you have a general statement to present, which we will follow with questions and discussion.

We are also glad to have before us the Chairman of the Commission, Mr. McCone, and a member of the Commission, Dr. Libby, this morning.

I believe you are prepared to start, Dr. Dunham, unless, Mr. Chairman, you wish to make a statement.

Mr. MCCONE. No, sir; I have no statement to make, Mr. Chairman.

Representative VAN ZANDT. At this point, Mr. Chairman, could we put in the record this glossary of technical terms? I am thinking now of the laymen who may read these hearings when they have been printed and distributed.

Representative HOLIFIELD. Without objection, that will be received in the hearing at this point.

(The document referred to follows:)

GLOSSARY OF TERMS

Alpha particle	A fundamental particle resulting from radioactive decay, consisting of two protons and two neutrons and possessing kinetic energy or energy of motion. The energy of an alpha particle is measured in million electron volts. Abbreviated: Alpha.
Average or mean life	The actual life of any particular radioactive atom, can have any value between zero and infinity. The average or mean life of a large number of atoms, however, is a definite quantity and is equal to 1.44 times the half life.
Beta particle	A fundamental particle resulting from radioactive decay. It consists of a negatively charged electron possessing kinetic energy or energy of motion. Beta particle energies range from kilo electron volts to million electron votes. Abbreviated: Beta.

Biological half-life—The biological half life of any element or radioactive nuclide is the time interval required to reduce the number of atoms present in the body to half of their initial value. The biological half life does not include the radioactive half life of a radioactive element.

Curie—That quantity of a radioactive nuclide disintegrating at the rate of 3.70 by 10^{10} atoms per second or 2.22 by 10^{12} atoms per minute. Abbreviated: c.

Micromicrocurie—One million millionth of a curie or that quantity of a radioactive nuclide disintegrating at the rate of 3.7 by 10^{-2} atoms per second or 2.22 atoms per minute. Abbreviated; $\mu\mu$c.

Millicurie—One thousandth of a curie or the quantity of a radioactive nuclide disintegrating at the rate of 3.70×10^{7} atoms per second or 2.22×10^{9} atoms per minute. Abbreviated: Mc.

Megacurie—One million curies or the quantity of a radioactive nuclide disintegrating at the rate of 3.70×10^{16} atoms per second or 2.22×10^{18} atoms per minute. Abbreviated: Mc.

Dose—The radiation delivered to a specified area or volume or to the whole body.

Effective half life—The time required for a radioactive element in the body to be diminished to half of its value as a result of the combined action of radioactive decay and biological elimination.

Electron volt—A unit of energy equivalent to the amount of energy gained by an electron in passing through a potential difference of 1 volt. Larger multiples of the electron volt are frequently used, viz, Kev. for thousand or kilo electron volts; Mev. for million electron volts; and Bev. for billion electron volts.

Erg—Unit of work or energy done by a unit force acting through unit distance. The nuclear unit of work or energy is the Mev. which is equal to 1.6×10^{-6} ergs.

Gamma ray—Electromagnetic radiation resulting from radioactive decay. Gamma rays have no mass and no charge, but have energy which ranges from Kev. to Mev.

Half life—The half life of a radioactive atom is the time interval over which the chance of survival is exactly one-half. In any large number of disintegrating radioactive atoms half of the atoms present at any time will decay during one-half life. The half life for a particular nuclide is given by

$$t_{\frac{1}{2}}=\frac{0.693}{\lambda}$$

where λ is a constant for each nuclide.

Biological half life	The biological half life of any element or radioactive nuclide is the time interval required to reduce the number of atoms present in the body to half of their initial value. The biological half life does not include the radioactive half life of a radioactive element.
Effective half life	The time required for a radioactive element in the body to be diminished to half of its value as a result of the combined action of radioactive decay and biological elimination.
Radioactive half life	The half life of a radioactive atom is the time interval over which the chance of survival is exactly one-half. In any large number of disintegrating radioactive atoms half of the atoms present at any time will decay during one-half life. The half life for a particular nuclide is given by $\dagger \quad \frac{1}{2} = \frac{0.693}{\lambda}$ where λ is a constant for each nuclide.
Stratospheric half life	The time interval required to reduce the activity present in the stratosphere to half by removal from the stratosphere to the troposphere. Stratospheric half life does not include radioactive half life of any of the radioactive nuclides.
Isotope	An isotope is the individual species of atoms in an element having a certain mass. For example: U^{238}, U^{234}, and U^{235} are isotopes of uranium.
Kilo electron volt	See electron volt.
Mean or average life	The actual life of any particular radioactive atom can have any value between zero and infinity. The mean or average life of a large number of atoms, however, is a definite quantity and is equal to 1.44 times the half life.
Megacurie	1 million curies or the quantity of a radioactive nuclide disintegrating at the rate of 3.70×10^{16} atoms per second or 2.22×10^{18} atoms per minute. Abbreviated: Mc.
Micromicrocurie	1 million millionth of a curie or that quantity of a radioactive nuclide disintegrating at the rate of 3.7×10^{-4} atoms per second or 2.22 atoms per minute. Abbreviated: $\mu\mu$c.
Millicurie	1 thousandth of a curie or the quantity of a radioactive nuclide disintegrating at the rate of 3.70×10^{7} atoms per second or 2.22×10^{9} atoms per minute. Abbreviated: Mc.
Million electron volts	See electron volt.

Nuclide	A nuclide is the individual species of atoms in an element having a certain mass and a specific energy content. Therefore, more than one nuclide may compose an isotope. For example, Ba–137m (radioactive) and Ba–137 (stable) are nuclides of the same isotope.
Rad	The unit of absorbed dose, which is 100 ergs per gram. The rad is a measure of the energy imparted to matter by ionozing radiation per unit mass of irradiated material at the place of interest. It is a unit that was recommended and adapted by the International Commission on Radiological Units at the Seventh International Congress of Radiology, Copenhagen, 1953.
Relative biological effectiveness	The ration of gamma or X-ray dose to the dose that is required to produce the same biological effect by the radiation in question.
REM	Roentgen equivalent man: that quantity of any type ionizing radiation which when absorbed by man produces an effect equivalent to the absorption by man of 1 roentgen of X- or gamma radiation (400 KV).
REP	Roentgen equivalent physical: the amount of ionizing radiation which will result in the absorption in tissue of 83 ergs per gram. (Recent authors have suggested the value of 93 ergs per gram.)
Stratosphere	The upper portion of the atmosphere, above (11 km), more or less (depending on latitude, season, and weather) in which temperature changes but little with altitude and clouds of water never form, and in which there is practically no convection.
Stratospheric half-life	The time interval required to reduce the activity present in the stratosphere to half by removal from the stratosphere to the troposphere. Stratospheric half life does not include radioactive half life of any of the radioactive nuclides.
Strontium unit	Formerly sunshine unit. One-thousandth of the maximum permissible body level of Sr–90. It is equal to 1 micromicrocurie per gram of calcium.
Tropopause	The imaginary boundary layer dividing the upper part of atmosphere, the stratosphere, from the lower part, the troposphere. The tropopause normally occurs at something like 35,000 to 55,000 feet altitude, although it depends on season and location.
Troposphere	All that portion of the atmosphere below the stratosphere. It is that portion in which temperature generally rapidly decreases with altitude, clouds form, and convection is active.

Representative HOLIFIELD. You may proceed, Dr. Dunham.

STATEMENT OF DR. CHARLES L. DUNHAM,[1] DIRECTOR, DIVISION OF BIOLOGY AND MEDICINE, U.S. ATOMIC ENERGY COMMISSION

Dr. DUNHAM. Chairman Holifield, I am honored to have been chosen as the first witness in this continuation of the series of hearings on radioactive fallout which began in June of 1957. Much has occurred in the past 2 years which it is well to bring before you. The pattern of testing has changed, i.e., large weapon testing is no longer predominantly near the equator. The rate of fallout during the past 12 months and especially the past 4 months has increased. The levels of strontium 90 in food and man have risen, and finally new information has been developed on global fallout patterns, on the behavior of strontium 90 and cesium 137, and other fallout nuclides in soil and plants, and on the biological effects of radiation.

Fallout is an inevitable consequence of nuclear weapons test which are carried out on the surface of the earth or in the atmosphere up to altitudes upwards of many thousands of feet. Those immediately concerned with weapons development have made it one of their prime objectives to develop methods for reducing fallout. This is particularly evident with the development of methods for testing underground. Rainier shot in the Plumbbob series was the first and a successful trial of this approach, and as you know in the Hardtack II series several other underground tests were conducted from which there was no radioactive material deposited off the test site. During the past few years I have watched carefully the changing fallout picture, and it has been good to know from where I sit as Director of the Division of Biology and Medicine that we now have a method for meeting some of our weapons development needs without producing additional fallout in the face of rising levels of contamination.

In order that the public be kept currently and fully informed on the subject of fallout and its possible consequences the AEC is constantly making public new information as rapidly as possible. Some information, as your committee knows, is of such a nature that it is much more important to hold it classified because of undue risk to the common defense and security than to release it. The AEC does not carry exclusively the responsibility in this area. Other agencies, including the CIA, DOD, and the State Department, are directly concerned.

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Education: B.A., Yale University, 1929; M.D., Rush Medical College, University of Chicago, 1933.
Experience: Internal medicine, Billings Memorial Hospital, University of Chicago, 1934; assistant resident in medicine, New Haven Hospital, Yale University, 1935; assistant in medicine, University of Chicago, 1936–41; instructor in internal medicine, University of Chicago, 1941–43; U.S. Army, Medical Corps, 1943–46; assistant professor of medicine, University of Chicago, 1946–49; Assistant Chief, Medical Branch, Division of Biology and Medicine, U.S. Atomic Energy Commission, 1949–50; Chief, Medical Branch, Division of Biology and Medicine, U.S. Atomic Energy Commission, 1950–54; deputy director, Division of Biology and Medicine, U.S. Atomic Energy Commission, 1954–55.
Affiliations: New York Academy of Sciences; American Association for Advancement of Science; National Cancer Chemotherapy Committee; AEC representative, Division of Medical Science, National Academy of Sciences, National Research Council; Radiation Research Society; Health Physics Society; Industrial Medicine Association; Radiation Study Section, National Institutes of Health, U.S. Public Health Service; National Committee on Radiation Protection; American Rheumatism Association; Interdepartmental Committee on Scientific Research and Development; Sigma Xi.
Publications: 15 scientific articles. Topics deal mainly with atomic-energy activities in medicine and medical research and more specifically effects of ionizing radiation on human beings, etc.

Following the issuance of the Health and Safety Laboratory Report No. 42 in October 1958, which is a large summary report entitled "Environmental Contamination from Weapon Tests," the Health and Safety Laboratory began publication of quarterly technical reports on worldwide fallout that are made available for sale through the Office of Technical Services. Many other reports originating in the various AEC laboratories (examples are UCRL–8083, "Estimation of Turnover Equation of Strontium 90 for Human Bones," by P. Durben and H. Jones; ANL–5920, "The Stratospheric Strontium 90 Fallout," by P. K. Kuroda; and BNL–496, "The Distribution of Fallout Activity in Rainfall at BNL, June-September 1957," by F. P. Cowan and J. Steimers) are also made available for sale.

From time to time the AEC issues special fallout reports through the Government Printing Office (examples are "Some Effects of Ionizing Radiation on Human Beings," 1956, by E. P. Cronkite, V. P. Bond, and C. L. Dunham; and "Radioactive Contamination of Certain Areas in the Pacific Ocean from Nuclear Tests," 1957, by G. M. Dunning). In 14 issuances of the semiannual reports of AEC, there were sections on fallout problems (examples are semiannual reports to the Congress, Nos. 14, 16, 19, 22, and 23). Scientific papers prepared by biophysical, biological, and medical scientists supported by AEC appear in many dozens of technical journals throughout the world. Papers specifically on worldwide fallout prepared by employees of AEC or by Dr. Libby have appeared in scientific journals (examples are "The Biological Hazard to Man of Carbon 14," Science, December 1958, by Totter, Zelle, and Hollister; [1] "Long-Term Fallout," Science, August 1958, by M. Eisenbud and J. H. Harley; and "Radioactive Fallout and Radioactive Strontium," Science, 1956, by W. F. Libby). The United States has been the principal source of fallout information to the U.N. Scientific Committee, largely because of the extensive data made available by the AEC. In addition, the AEC now plans to establish a system of regular quarterly public information releases on fallout so that information will be made available to the public not only via scientific and technical reports and speeches, as is now the case, but also in readily understandable summary form.

In order to make doubly certain that information within the purview of the AEC, which could be used by the public in the evaluation of radiation hazards, is not needlessly withheld or is reasonably accessible, Chairman McCone recently directed a complete review of all documents which contain information about radioactivity in the environment. All the classified documents that can be declassified, with or without deletion, have been so declassified and unless the information contained is already available in other documents, these declassified documents are being made available for distribution through AEC Technical Information Services and for sale through the Office of Technical Services. Previously declassified and unclassified documents will be made available in the same way and under the same rule. All of these documents that are being made available will be abstracted in the AEC's regular publication, Nuclear Science Abstracts. We recognize the need for public education in these matters and fully expect that the continuation of these hearings on fallout

[1] See vol. 3, app. G.

will prove to be another important contribution to our common endeavor to educate and to keep the public informed. The published report of these hearings should provide a new body of up-to-date knowledge on the subject as did the report of the 1957 hearings.

In my testimony I wish to inform your committee on the nature of our fallout studies and how they are conducted, to discuss the current situation concerning fallout and its distribution, to highlight new knowledge gained by our research efforts, and to restate for you the problem of permissible levels of radiation exposure.

Before proceeding, however, I would like to defer for the moment discussion concerning fallout and its distribution and state the situation as we see it today with respect to the biological effects of fallout. There is still a paucity of relevant information on man with respect to the effects of the low dose rates and the low total dose rates and the low total doses which we are concerned with today. For instance, the U.N. Scientific Committee on Radiation Effects, after reviewing all the available data, found itself unable to make a categorical statement on leukemia. It pointed out that the data permitted of a threshold for leukemia induction as high as several hundred roentgens. At the same time that committee gave estimates of the number of cases of leukemia which might occur were the effect linear with dose regardless of dose rate. They did the same for bone cancer but in addition noted that whereas radiologists in this country appear to have a higher incidence of leukemia than do nonradiologists presumably from exposure to X-ray, no corresponding increase in bone cancer has been noted even though the absorbed dose of radiation in bone was probably greater than that to the bone marrow. Meanwhile, the Russells' work at Oak Ridge has clearly demonstrated a dose rate dependence for gene mutation induction.

Representative HOLIFIELD. Will you please explain that last sentence, Dr. Dunham?

Dr. DUNHAM. Yes, Mr. Holifield. This means that if one exposes the germ cells to radiation of a given dose level, say 100 or 200 roentgens, and this exposure takes place almost instantaneously, the effect is some four times as great as it was if the exposure was at a much lower dose rate.

Representative HOLIFIELD. And over a longer period.

Dr. DUNHAM. And over a longer period of time, yes.

Representative HOLIFIELD. This, then, would mean that in the case of an exposure to nuclear weapons, that would be an instantaneous and high level exposure.

Dr. DUNHAM. That is correct.

Representative HOLIFIELD. And it would be more dangerous than an amount of radioactivity which a worker might get in a plant over a number of years, even though it were the same amount?

Dr. DUNHAM. That is correct, sir.

Earlier estimates indicated that continued testing at a rate comparable to that preceding 1958 would result in a 30-year gonadal dose of from 0.1 to 0.13 r. in the United States. More recent heavy fallout, principally from the Russian tests, would increase this estimate if the rate and type of testing as conducted during 1958 were maintained.

During the past year there has fallen out across much of the United States nearly 20 microcuries of strontium 90 per square mile, about twice the amount which has fallen out in any prior 12-month period. As a result we are seeing substantial increases in levels of strontium 90 in milk and other foods. To what extent these increases will continue during the next year is uncertain. In any event these increases will be reflected in increases in the average strontium 90 content of young children which have been observed to be about two strontium units in early 1958.

Representative HOLIFIELD. Is there any way you can explain, so that the public can understand, the relative amount between millicurie and a curie, and then relate it to the exposure one would get from an X-ray? Is there any kind of example you could give us at this time, because when a headline says that the amount of strontium 90 has doubled, the headline scares a great many people? Is there any way now that you can explain in laymen's terms so we can understand what we are talking about when we talk about microcuries and millicuries?

Dr. DUNHAM. First, I might say when you double a small amount you still have a small amount. I think this is very important to keep in mind. A millicurie is one-thousandth of a curie, which is the amount of radioactivity contained in a gram of radium. A microcurie is one-millionth of a curie. A micromicrocurie, which is the unit often used in assessing the amount of strontium 90 in foods, is a millionth of a millionth of a curie. Does this help?

Representative HOLIFIELD. This explains it factually. I hope that the public will understand that in using either millicuries or microcuries or micromicrocuries we are dealing in a very, very small, infinitesimal amount of material.

Dr. DUNHAM. Yes. We are talking about amounts of radioactivity which occur not infrequently in nature in certain areas of the world.

Representative HOLIFIELD. In other words, the normal background is measured ordinarily in small measurements such as this.

Dr. DUNHAM. That is correct, sir.

Representative HOLIFIELD. The normal background of radioactivity, I understand, has been computed to amount to 7 roentgens over a 70-year-lifetime accumulative.

Dr. DUNHAM. Yes.

Representative HOLIFIELD. So your normal background that a man would accumulate—and this is an average—it might be somewhat higher in the monazite sands in India or Brazil, or the radium ore-bearing areas of the West than it would be at sea level. It would be higher at Pikes Peak because of the cosmic rays than at sea level.

Dr. DUNHAM. Yes.

Representative HOLIFIELD. This is an average amount which has been considered to be accurate, that human beings would accumulate in 70 years from normal background radioactivity 7 roentgens.

Dr. DUNHAM. Yes.

Representative HOLIFIELD. Can we relate that to the fluoroscopic exposure of a whole body fluoroscopic examination? Is there any way of doing that?

Dr. DUNHAM. Normally they don't fluoroscope the entire body. On the other hand, a careful fluoroscopic examination of the gastrointestinal tract, studying an ulcer of the stomach or looking for a

cancer, might involve several roentgens to the general area of the abdomen.

Representative HOLIFIELD. And a full molar X-ray of the mouth, how much would that ordinarily run?

Dr. DUNHAM. It depends on the antiquity of the X-ray machine. It may run anywhere from 10 or 12 roentgens to as much as 80 to the jaw.

Representative HOLIFIELD. As much as 80 roentgens, Dr. Dunham, to the jaw?

To make it clear, this is a spot exposure. It is not a whole-body exposure as you would have in the roentgens of normal background radioactivity.

Dr. DUNHAM. That is right.

Representative VAN ZANDT. Doctor, have you established a normal exposure for the military, based on the physical examinations and other exposures they are subjected to?

Dr. DUNHAM. I do not know of such a figure. I am sure the military services, particularly at the time of induction, have routine chest X-rays. I do do not think they have routine gastrointestinal studies and that sort of thing. In terms of total body exposure it would probably not be very large. Certainly in terms of the exposure of the germ cells it would not. It would probably have a few milliroentgens.

Representative VAN ZANDT. Therefore, your statement applies to our population in general.

Dr. DUNHAM. Yes, sir.

Representative VAN ZANDT. It would include those persons who took advantage of the Red Cross X-raying of lungs and so forth.

Dr. DUNHAM. That is correct.

Representative VAN ZANDT. Thank you.

Representative HOLIFIELD. You may proceed.

Dr. DUNHAM. It is possible that the average body burden of strontium-90 in young children over much of the United States could rise to 10 strontium units from testing to date.

I have just taken this as a possibility, and I want to do a little calculating from this point on. The skeletal dose corresponding to this level would be approximately two rads. In other words, two roentgens. At this point I would like to introduce into the record a paper by Dr. Willard F. Libby, entitled "Bone Doses From Strontium 90," which was published in the papers from the geophysical laboratory of the Carnegie Institution of Washington in February 1959.

(The document referred to appears on p. 51.)

Dr. DUNHAM. Bearing these dose estimates in mind, one can, on the basis of one current theory estimate a maximum number—and I underline the words "maximum number"—of additional cases of bone cancer per year in the next 70 years of from 50 to 100 and for leukemia it might as much as double that figure. Of course, there may be no additional cases at all, as the U.N. Scientific Committee was so careful to point out. Genetic effects during the next 30 years would average not more than 20 persons born each year with tangible genetic defects and several times that number with lesser genetic defects, stillbirths, and the like.

In meeting with the seminar group which you asked us to call, I suspect this estimate is a little high. I think the figure they are

coming out with of gonadally significant exposure from tests today is lower than I used.

Representative HOLIFIELD. I understand that testimony will be made available to the committee.

Dr. DUNHAM. Yes, sir. In this country there would occur not more than 500 greater or lesser tragedies of this nature to add to the same 1,400 fatalities and a large number of serious injuries each year readily identifiable with other aspects of our defense efforts. If weapons tests that produce fallout are not resumed these rates if realized at all would gradually subside with succeeding generations.

Representative HOLIFIELD. I think at this point we might say you are testifying to the effects up to date.

Dr. DUNHAM. That is correct, sir, in this country.

Representative HOLIFIELD. This does not look into the future, of course, and if testing does continue and if it continues at the same rate as the last year of testing, or if it builds up at an increased rate, then the situation would be different.

Dr. DUNHAM. That is correct, sir.

Representative HOLIFIELD. We are going to have testimony later on that point.

Dr. DUNHAM. During the past few weeks I have reviewed the record of the 1957 hearings. It is a remarkable document containing not only the testimony of many outstanding scientists who appeared before your Special Radiation Subcommittee of the JCAE, and statement submitted by them for the record, but also a large amount of supplementary material gathered by the staff of your committee. In the summary analysis (p. 1) the following note appeared:

> The hearings, including material introduced for the record and a comprehensive bibliography, will probably be the most extensive library of information on fallout yet to appear in one document.

There is no doubt that that has been the case. The hearings covered not only the production and dissemination of fallout but also the biological effects of radiation in general.

In my contacts with the United Nations Scientific Committee during the past 2 years, it has been apparent that this two-volume record plus its comlete index provided a basic document rivaled in significance only by the 1956 report of our own National Academy of Sciences and that of the British Medical Research Council.

Representative VAN ZANDT. Mr. Chairman, may I interrupt at this point and tell the doctor that to date we have distributed about 20,000 copies of the 1957 hearings? I think this is indicative of the great interest demonstrated by the people of the United States as well as nationals of other countries.

Dr. DUNHAM. This is absolutely correct. I was in Europe last summer and I found that anybody who had any interest in this problem was going back to that as sort of a source book.

Representative HOLIFIELD. Dr. Looney, who was a witness in those hearings, was in my office about 2 weeks ago. He is on a scholarship at Cambridge, and he is going back for another year of scholarship. He said that he was approached by a scientist from Prague who was also taking the same course in Czechoslovakia, and he asked him if it was possible for him to get these two volumes of the hearings. He said he thought it would be. He got them and gave them to this

scientist in Prague. The scientist evinced great appreciation. He said, "These are priceless documents. We have nothing behind—" then he said—"nothing in Prague." He started to say "nothing behind the Iron Curtain." It is a valuable document in many places of the world.

Dr. DUNHAM. Definitely.

One of the significant contributions of the 1957 hearings was that they repeatedly emphasized the importance of distinguishing between incontrovertible fact and value judgment. They served to make it clear that such words as "clean" and "safe" and even the word "hazardous" each have absolute connotations and the use of them in a scientific discussion in less than the absolute sense defies exact definition and serves to confuse. Your committee noted general agreement on several points: First, you noted with respect to the origin of fallout that all nuclear explosions must be expected to produce radioactive materials.

You noted further that although there is no such thing as an absolutely "clean" weapon (that is, there is no such thing as a nuclear weapon detonation completely free of accompany radioactivity), the amount of the radioactivity can be substantially altered in relation to the size of the explosion. It is interesting to note that although there were a number of references to the production of carbon 14 (which is produced as radioactive carbon dioxide), no appreciable significance was attached to this from the standpoint of hazard. Since the hearings the matter of the hazard of C–14 has come up and the Division of Biology and Medicine has issued WASH–1008 (reprinted in Science in December) on this subject. Further comments on this subject are embodied in a statement by Dr. Max Zelle of my staff as appendix A to my statement (p. 56).

(Also see WASH–1008, in vol. 3, app. G.)

Representative VAN ZANDT. At this point, could you spend a few minutes explaining what you mean by a clean weapon? Thinking of the layman now, who will read these hearings.

Dr. DUNHAM. As I indicated, Congressman, one should not use this word in an absolute sense, because no atomic device can be detonated without producing some radioactivity. The Commission and those concerned with the development of nuclear devices have developed a whole range of weapons which produce greater or lesser amounts of radioactivity. This we feel is an important development.

Representative VAN ZANDT. In other words, then, a clean weapon is one that produces lesser amounts of radiation than a dirty weapon?

Dr. DUNHAM. Yes.

Representative HOLIFIELD. Mr. Ramey has a question.

Mr. RAMEY. Have the Russians been testing any clean weapons?

Dr. DUNHAM. This is something that I don't believe I can comment on. I think one would have to get that information from another agency.

Mr. RAMEY. Have the results of the Russian tests been rather dirty in the sense of radioactivity?

Dr. DUNHAM. There has been a great deal of radioactivity released from the fall Russian tests.

Representative HOLIFIELD. There will be more testimony on this later, and some of the causes for this will be explored at least from the standpoint of the information which we have. I think it will be

interesting to the American public to find some of the facts that are involved in this.

Dr. DUNHAM. Yes.

Representative VAN ZANDT. Mr. Chairman, would the doctor continue to explain whether or not the clean weapon involves fission or fussion?

Dr. DUNHAM. I think the problem is again the use of the word "clean." The relative amounts of fission products that is really one of the biggest elements in this matter whether or not a weapon is——

Representative HOLIFIELD. Any question that is propounded, we expect the witnesses to observe the rules of security.

Dr. DUNHAM. Yes, sir.

By now it is abundantly clear that the distribution of fallout is not uniform in the environment. Much more data are available now on the amounts of strontium 90 and cesium 137 and other bomb-produced radioactive debris in the atmosphere, in soils, in foods, and in man himself.

Your terse comment on the effects of nuclear war which read as follows:

> **The catastrophic nature of the radiation effects from a multiweapon (atomic and hydrogen bombs) attack on the United States were clearly portrayed. This, of course, could be applied to any nation—**

serves to highlight all-out nuclear war which must be the backdrop for any consideration of the question of whether or not our weapons testing program with the fallout it has produced is resulting in a net gain for our people and those of the free world.

Before taking up point by point the "major unresolved questions" as enumerated in your summary statement, we would like to comment on AEC's program of research on fallout per se and those other researches which are aimed at developing more precise understanding of the hazards of exposure to ionizing radiation and the hazards of contamination of the environment with radioactive materials.

(The summary of program follows:)

U.S. ATOMIC ENERGY COMMISSION, DIVISION OF BIOLOGY AND MEDICINE

Research project and budget summary

	Actual fiscal year 1958	Estimated fiscal year 1959	Estimated fiscal year 1960
Fallout sampling and analysis	$1,708,573	$2,648,000	$3,564,000
Program activities related to the development of radiation standards	25,155,251	30,898,000	34,902,000
Research related to radiation standards of permissible exposure (radiation biology)	15,738,263	18,760,000	21,134,000
Research related to radiation standards involving environmental contamination and waste disposal	2,708,122	4,064,000	4,499,000
Research related to prophylaxis and treatment of radiation injury	3,150,623	3,632,000	4,059,000
Dosimetry and instrumentation	2,027,703	2,083,000	2,267,000
Radiation protection, physical	867,616	1,440,000	1,762,000
Radiation measurements, general	662,924	919,000	1,181,000
Additional research including beneficial applications of atomic energy	8,474,246	9,696,000	10,534,000
Total biology and medicine program	35,338,070	43,242,000	49,000,000

Dr. DUNHAM. I direct your attention to a summary of this program which follows in your text.

Senator PASTORE. Mr. Chairman, may I ask a question?

Representative HOLIFIELD. Senator Pastore.

Senator PASTORE. Doctor, before you get to that point, taking you back to page 8 and the sentence you just read, "By now it is abundantly clear that the distribution of fallout is not uniform in the environment," would you say, Doctor, that the one mistake that was made in the calculations as to the radiation and its harmful effects was predicated upon the fact that it was speculated by those who ventured opinions that the fallout was in a sense uniform in the whole atmosphere, and for that reason had a certain thinning-out effect which was less harmful than if you had concentration in certain parts of the hemisphere?

Dr. DUNHAM. I don't think that any model which was developed which was predicated on a relatively uniform distribution ever ignored the fact that tropospheric fallout, particularly fallout from weapons tests in Nevada, or the tropospheric fallout from the tests in the Pacific, would not be distributed in a relatively uneven fashion. There was evidence of that very early with the fallout on Troy, N.Y., back in 1953, I believe, a rainout following a test in Nevada.

Senator PASTORE. Let me go a step further. Let me include the stratosphere.

Dr. DUNHAM. Can you repeat the question, Senator, to get my train of thought back?

Senator PASTORE. My question is this: There seems to have been a change in attitude on the part of the scientists who have spoken out with relation to the hazards involved with regard to fallout.

Dr. DUNHAM. Yes, sir.

Senator PASTORE. Many of them have become a little more cautious in their point of view as to what harmful effects were being distributed to mankind, and to the topography as well. Many of them who were more or less liberal in their point of view as to the amount of harm that was being done, speculated, wouldn't you say, on the calculation that there was a certain uniformity in the fallout, out of the stratosphere, with relation to the whole globe as against the further discovery later on that much of this was concentrated, and there was a phenomenon involved that could not be explained, as to how this cloud would gather and that it would come down in more density in some part of the universe than in others.

Dr. DUNHAM. I think there was a good deal of discussion of that at the last hearings, as you recall. One of the models was one which assumed a relatively uniform distribution in the stratosphere with subsequent relatively uniform fallout. On the other hand, other points of view were well expressed at that time.

Senator PASTORE. This leads me to the precise question that I would like to ask of you, Doctor. Has that point of view become fortified with the evolution of time as of today?

Dr. DUNHAM. I would not like to anticipate some very expert testimony you are going to have this afternoon, but I would say that generally the nonuniformity has become more and more apparent, particularly with respect to materials injected at different latitudes.

Senator PASTORE. And the better accepted theory?

Dr. DUNHAM. I think we know a lot more about it; yes, sir.

Representative HOLIFIELD. You submitted a chart here on page 10.

Dr. DUNHAM. Yes.

Representative HOLIFIELD. We will come back to that chart later and discuss it. Is it Friday we will have testimony on that?

Mr. RAMEY. Yes, sir; and what the various agencies are doing and what funds they are spending, and so on.

Dr. DUNHAM. The Division of Biology and Medicine has kept informed of the vast amount of information being developed for other purposes and has concentrated its own additional research efforts on trying to see to it that those additional things were done which needed doing to enable us to get a complete picture of fallout.

It must be borne in mind that some of the most valuable information we have on the movement of fission products in the air or the soil and the deposition of vegetation and soil of particulate or gaseous radioactive material comes as a byproduct to two major housekeeping activities. These are budgeted quite properly not as research but as part of the operating cost at production and processing plant sites or at weapons test sites of either radiation safety activities, diagnostic studies of weapons, or studies aimed solely at being better able to predict the trajectories of tropospheric fallout. For instance, at each Pacific proving ground weapons test series the joint task force has spent several million dollars on documentation of near-in fallout. This has in turn provided information on how much material was deposited nearby and how much remained behind in the atmosphere to fall out later as tropospheric or stratospheric fallout. Sampling of the radioactive mushroom clouds has provided information on particle size as well as the relative amounts of strontium 90 as a function of particle size. None of these activities is budgeted under the Division of Biology and Medicine program. How much this total effort has been a cooperative one, and one which has avoided gross duplication of effort and wasted money, can be seen from the way our stratospheric balloon collection program has been handled. It is budgeted at less than a million dollars only because we obtained an equivalent amount of logistic support from the armed services. I refer particularly to tracking and recovery of the balloons especially those that come down over water.

The AEC's Division of Biology and Medicine sponsored program of research into the nature and hazards of fallout has grown steadily during the past 2 years as your committee recommended in 1957. It has expanded by nearly 50 percent costwise. The intensity of the effort has increased even more so. I am providing a tabulation of this entire program for the record which outlines in detail the full extent of research in these important matters as well as in closely related activities.

I believe that tabulation has been delivered to the committee (see vol. 2, p. 1829.)

Representative VAN ZANDT. Mr. Chairman, I would like to ask the Doctor at this point, how much have we spent in this field to date in round figures under the supervision of the AEC.

Dr. DUNHAM. In the field of fallout and the effects of fallout?

Representative VAN ZANDT. The effects of radiation hazard on man.

Dr. DUNHAM. About $150 to $180 million, I think is the figure. I don't recall exactly. I can get you an exact figure.

Representative VAN ZANDT. You plan for fiscal 1959—and I understand this will be discussed a little later—about $20 million, is that correct?

Dr. DUNHAM. In 1959 we will be spending in research, an additional $4 million on research related to standards involving environmental contamination.

Representative VAN ZANDT. That would be $22 million?

Dr. DUNHAM. That would be 22 plus the monitoring activity.

Representative VAN ZANDT. In round figures how many people do you have working in this field?

Dr. DUNHAM. The total figures under "Research Related to Radiation Standards," 919 scientists in the current fiscal year. Scientific man-years.

Representative VAN ZANDT. How many technicians do you have supporting the 800 scientists?

Dr. DUNHAM. Roughly twice as many.

Representative VAN ZANDT. So you have a total of about 2,000?

Dr. DUNHAM. That is correct.

Representative VAN ZANDT. Is the AEC alone in this field or do you have other Government agencies working with you?

Dr. DUNHAM. By no means are we alone. We have support from the Public Health Service through its National Institutes of Health. We have support through their Bureau of State Services, Division of Radiological Health. We have support from the Department of Defense. As you know the Walter Reed Army Hospital has a fine program in radiation biology and so has the Navy at the Naval Medical Center and at the Naval Radiological Defense Laboratory.

Representative VAN ZANDT. Does this work reach beyond the Government.

Dr. DUNHAM. Definitely. Much of the work that the National Cancer Institute sponsors is done privately in universities and elsewhere.

Representative VAN ZANDT. Does it reach into the educational institutions and universities?

Dr. DUNHAM. Yes, sir. I don't have any concept—I don't know how you get the figure—how much private money is going into this through universities, but I understand it is considerable.

Mr. RAMEY. On your $18 or $20 million figure for fiscal 1959 and fiscal 1960, would most of this research be equally applicable to any type of radiation hazard, rather than fallout as such?

Dr. DUNHAM. That is correct, sir. These studies include the effects of X-rays, gamma rays, beta rays, alpha rays, and also some of this actually goes for the effects of neutrons. It is not too important which type of radiation one is talking about in terms of the answers we are getting.

Mr. RAMEY. So it might be just a little bit misleading for the idea to be gotten out that they are spending $20 million on fallout, as such, whereas actually you are spending, on your chart here, around $2 or $3 million on your sampling analysis and the rest on research affecting all types of radiation hazard?

Dr. DUNHAM. That is correct. I am glad you brought it out. That is why we have this set up this way, to make that distinction between

studies of fallout per se and the whole problem of radiation hazards as the Commission finds them.

Mr. RAMEY. You noted that since 1957 your fallout budget has gone up about 50 percent. Didn't the Biology and Medicine Division recommend a somewhat substantially increased budget than that initially?

Dr. DUNHAM. You mean the Advisory Committee?

Mr. RAMEY. And the Division of Biology and Medicine.

Dr. DUNHAM. My Division?

Mr. RAMEY. Yes.

Dr. DUNHAM. We had hoped to expand the program somewhat more rapidly, but we were never held down in terms of the funds available. It was the problem of getting the thing rolling. It was not due to limitation by the Commission on the funds available.

Senator PASTORE. How do you mean that, Doctor? Is there a lack of scientists to do the work?

Dr. DUNHAM. It is a problem to get these programs started. For instance, this new one on hog genetics at the University of Iowa, it has taken nearly 2 years of first getting scientific soundness into that program by conferring with geneticists all over the world and furthermore to actually work out with the university what is needed to go ahead with the program.

Senator PASTORE. I have a reason for asking my question. I don't know whether I may be anticipating, but you did mention the fact or a question was asked of you by Mr. Van Zandt that you are being supported by the Public Health Service?

Dr. DUNHAM. Yes, sir.

Senator PASTORE. What kind of support do you get?

Dr. DUNHAM. Could you repeat the question?

Senator PASTORE. There was a question asked by Mr. Van Zandt that you do receive support from the Public Health Service.

Dr. DUNHAM. No, sir. I meant support in terms of supporting work. They don't transfer money to the AEC.

Senator PASTORE. I am not speaking about money. I am speaking about support generally. What is the support that you do get?

Dr. DUNHAM. They have actually handled the radiation off-sight safety in Nevada for us under contract, with a transfer of funds with the AEC.

Senator PASTORE. The reason I asked you the question, Doctor, that several suggestions have been made that possibly that whole activity should be turned over to the Public Health Service. This leads me to the question that I should like to ask you. What would be the advantage or disadvantage of that?

Dr. DUNHAM. I understand this would be taken up later in the program.

Senator PASTORE. Then I am anticipating?

Dr. DUNHAM. I would like to interrupt at this point, if I may, Mr. Holifield.

Representative HOLIFIELD. I want to say that our outline contemplates taking these matters up on the last day, and this particular subject. We will have witnesses on this point. If we can follow the outline as closely as possible I think it will be a more orderly presentation. But anything that you wish to submit may be submitted.

Dr. DUNHAM. I would like to interrupt at this moment, I have just been advised that I can release certain figures on weapons yield.

Representative HOLIFIELD. You are departing from your regular testimony now to make this announcement; are you, Doctor?

Dr. DUNHAM. Yes, sir.

Representative HOLIFIELD. All right.

Dr. DUNHAM. I think these data will be tremendously valuable in making the discussions this afternoon much more meaningful to the public.

Representative HOLIFIELD. This is heretofore classified material?

Dr. DUNHAM. That is correct.

Representative HOLIFIELD. Which has been declassified and is now being distributed I think to the press at this time. Will you tell exactly what it does?

Dr. DUNHAM. It gives almost year-by-year total fission yield beginning 1945 for the United States and the United Kingdom, and beginning at 1952, it gives fission yield. It also gives information on the Soviet yields in terms of total fission yields for 1945 to 1951, 1952 to 1954, 1955, 1956, 1957 to 1958, each inclusive. It also breaks down again by groups of years, 1935 to 1951, 1952 to 1954, 1955 to 1956, 1957 to 1958, the fission yield in terms of whether or not the detonation was an airburst, which means essentially all the material would be placed in the stratosphere, or that it was a ground surface burst, or whether it was a water surface burst.

Representative HOLIFIELD. In the case of table No. 3, it shows the gradual increase in the release of fission, and it shows the airburst has gone up from 190 kilotons to 57,000 kilotons. It shows the surface burst has gone from 570 kilotons to 28,000 kilotons. To get the total amount you would add the 28,000 and the 57,000, would you not?

Dr. DUNHAM. Yes.

Representative HOLIFIELD. For the airburst and the surface burst?

Dr. DUNHAM. That is correct.

Representative HOLIFIELD. That would give us a total of approximately 85,000 kilotons that has been released?

Dr. DUNHAM. Yes.

Representative HOLIFIELD. The significant part of this, I think, is to show how the rate over the period of time from 1945 to 1958, of increase has occurred. This is the concern of this committee and it is the concern of many thoughtful people throughout the world, that is, if this rate of geometrical increase continues for the next 13 or 14 years in the same ratio as it has in the past 14 years, we will be getting to a very serious problem in the total release radioactivity into the earth's environment?

Dr. DUNHAM. Yes. If you are talking about the rate of increase this would be very definitely the case. I would like to call your attention to the table 3, that the right-hand part of the table is total yield, not fission yield. I would also like to call your attention to the footnote which points out that an arbitrary figure of 50 percent has been taken for the fission yield to total yield ratio for all Soviet thermonuclear tests.

Representative HOLIFIELD. It is interesting to note that in the concluding days of our hearings 2 years ago a seminar of scientists in

front of us in a panel suggested that the maximum permissible release into the world's atmosphere should be in the neighborhood of 10 megatons. If we add the 14 megatons and the 21 megatons on table 2, it gives us 35 megatons in the 1957–58 period.

Dr. DUNHAM. That is correct, sir.

Representative HOLIFIELD. Which is far beyond the maximum amount which was decided by the seminar would be a permissible amount.

Dr. DUNHAM. That is correct, sir.

(The material referred to follows:)

TABLE No. 1.—*United States and United Kingdom nuclear events*

[Yield in kilotons]

Year	Total fission yield	Total fission yield from events, the total yield of which was 1 megaton or greater
1945	60	
1946	40	
1948	100	
1951	500	
1952–54	37,000	36,000
1955	200	
1956	9,000	8,000
1957–58	19,000	14,000

TABLE No. 2.—*Soviet nuclear events*

[Yield in kilotons]

Inclusive:	*Total fission yield* [1]
1945–51	60
1952–54	500
1955–56	4,000
1957–58	21,000

[1] A value of 50 percent has been arbitrarily selected for the fission to total yield ratio for all Soviet thermonuclear tests. As indicated in the tables, 50 percent is about the average fission to total yield ratio for all United States and United Kingdom thermonuclear tests.

TABLE No. 3.—*United States, United Kingdom, and Soviet nuclear events*

[Yield in kilotons]

Inclusive years	Fission yield [1]			Total yield	
	Airburst	Ground-surface burst	Water-surface burst	Airburst	Surface burst
1945–51	190	550	20	190	570
1952–54	1,000	15,000	22,000	1,000	59,000
1955–56	5,600	1,500	6,000	11,000	17,000
1957–58	31,000	4,400	4,600	57,000	28,000

[1] A value of 50 percent has been arbitrarily selected for the fission to total yield ratio for all Soviet thermonuclear tests. As indicated in the tables, 50 percent is about the average fission to total yield ratio for all United States /United Kingdom thermonuclear tests.

Representative HOLIFIELD. You may proceed.

Dr. DUNHAM. The problem of rate and pattern of transport of fallout and its final distribution over the surface of the earth is primarily a meteorological one. The closest possible liaison with the Weather Bureau, the Air Force and the Armed Forces Special Weapons Project personnel and their related studies has been essential and has, I believe, been successfully achieved.

It will become apparent in later testimony that our present understanding of global fallout depends not on the activity of any one agency. On the other hand, we believe that the AEC has played a key role in developing this knowledge. It has encouraged, and where appropriate or necessary, supported financially those groups, both in and out of Government best qualified to work on various aspects of the problem.

For instance, it turns out as would be expected that the best evidence as to the ultimate resting place of global fallout is to collect and to analyze soil for Sr-90 on a global basis. This has been done by the untiring efforts of Dr. Alexander and others in the Department of Agriculture with analytical support by AEC's Health and Safety Laboratory.

Commissioner Libby and Mr. Eisenbud personally stimulated the worldwide pot and washtub collection network and made arrangements with scientists in Australia, New Zealand, and other countries to participate in our program.

Professor Kulp, of Columbia University, has for several years assumed responsibility for our national and worldwide human bone studies. He also has made studies in soil uptake of strontium 90 and collected and analyzed a variety of foods from many places in the United States and abroad. In our food collection program we had splendid cooperation from the Interdepartmental Committee on Nutrition which assisted our procurement of food from South America and other areas.

Recently at our request and with AEC-suport the USPHS has undertaken a regional study of Sr-90 in humans in the vicinity of the Nevada Proving Ground.

One of the critical parts of the program has been the analytical work. Our HASL has been responsible for developing methods and procedures based on Dr. Libby's pioneering work for analyzing Sr-90 in a variety of materials, soil, grass, water, air samples, etc. It has worked with the several contract laboratories on methods, standardization of procedures, and most important and at times most discouraging of all, the matter of quality control which has plagued those who have worked at the low levels we have to deal with in these fallout studies.

The program of fallout sampling and monitoring supported by the AEC has been quite comprehensive and at a cost of approximately $2.6 million for the current year will include:

I. Development of stratospheric and ground level sampling devices:	
Armour Research Foundation	$30,000
Chicago, University of, Midway Laboratories	25,000
Del Electronics Corp	50,000
General Mills, Inc	300,000
Georgia Institute of Technology	6,000
Meteorology Research, Inc	10,000
Western Precipitation Corp	50,000
Total	471,000
II. Stratospheric and surface air sampling and analysis:	
Air Force, U.S. Department of (Ashcan)	220,000
Health, Education, and Welfare, USPHS	75,000
Health and Safety Laboratory, NYOO [1]	150,000
Navy, U.S. Department of, Naval Research Laboratory [2]	40,000
Total	485,000
III. Measurement of fallout deposition on the earth's surface and measurements of fallout on and in plants and animals, including man:	
Agriculture, U.S. Department of	47,000
Air Force, U.S. Department of Air Research and Development Command	50,000
Arkansas, University of	21,000
California, University of, at Los Angeles	273,000
Columbia University, Lamont Geological Observatory [2]	150,000
General Electric Co., Hanford Atomic Products Division	200,000
Health, Education, and Welfare, U.S. Department of, NIH	4,000
Health, Education, and Welfare, U.S. Department of, Bureau of State Services	26,000
Health and Safety Laboratory, NYOO [1 2]	600,000
Interior, U.S. Department of, Geological Survey	30,000
Los Alamos Scientific Laboratory [2]	25,000
Miami, University of, Marine Laboratory	20,000
Michigan, University of	12,000
Mount Washington Observatory	4,000
New Zealand, Government of	10,000
Washington, University of, Applied Fisheries Laboratory [2]	140,000
Total	1,612,000
IV. Compilation and meteorological interpretation of fallout data:	
Commerce, U.S. Department of, Weather Bureau	80,000
Total	2,648,000

[1] Split function.
[2] Radiochemical analyses are a part of programs denoted by footnote 2.

This program has been primarily a scientific research program with the purpose of understanding the factors that influence the patterns and rates of fallout onto the earth's surface whether the debris is tropospheric in origin or stratospheric and whether the fallout material originates near the Equator or at some other latitude. This has meant sampling longitudinally, latitudinally, and vertically.

What has been demanded is four dimensional sampling, in two dimensions over the surface of the earth, a third dimension out to 100,000 feet or more in the earth's atmosphere, and a fourth in time. The program would be nowhere today without the cooperation, the initiative, and imagination of scientists here and abroad working either with AEC support or with funds from their own or other agencies. Special mention should be made of the work of the United Kingdom scientists who have cooperated and exchanged data and ideas with us in a most constructive manner.

Last September, 10 of us from this country spent a week at Harwell with the United Kingdom scientists bringing each other up to date on the data and exploring all scientific aspects of the problem both physical and biological and even to some extent the public and international relations aspect of the problem.

As I indicated above the sampling aspects of our program were primarily part of a scientific study aimed at learning all we could about fallout and understanding it sufficiently well to be able to predict in advance the eventual distribution and concentration of fallout radionuclides in the biosphere including man.

From the very beginning, however, there were two other aspects of the study which have become increasingly important as time has passed and the accumulation of strontium 90 in the food chain and in man has increased. They are are public health and the public relations aspects of the problem. Our HASL established its gum paper network about the country as early as 1951, for two purposes. One was scientific, the other was to let us know of any areas where unusual amounts of fallout had occurred.

By 1956, 39 stations were operating in the United States and 66 in other countries. On April 1954 the first of a continuing series of monthly analyses of powdered milk from Perry, N.Y., was made. In May 1955 Columbus, Wis., was added as representative of the Chicago milkshed. Sampling and analysis of powdered milk from Mandan, N. Dak., and wet milk in the New York City market was inaugurated at about this time. A few spot samples were run from Missouri and Oregon in 1955–56.

In April 1956, prior to Operation Redwing the AEC requested the USPHS to establish with AEC funds a radiation surveillance air-sampling network involving some 29 stations including one each in Hawaii and Alaska. These were to supplement AEC's own surveillance program at its major sites set up to provide prompt coverage on air concentrations of fallout during periods of weapons testing. A similar but more extensive network was established prior to Operation Plumbbob in the spring of 1957. It included 38 USPHS stations and 11 AEC stations. This network has operated continuously to date.

As was brought out in your 1957 hearings the AEC with assistance from the Department of Agriculture had already analyzed a number of common market vegetables with a view to ascertaining whether or not there was any unusual discrimination in favor of or against strontium 90 in certain of them. Nothing was observed which could not be explained on some basis other than true discrimination. Good evidence for direct contamination of surface crops by fallout was obtained. Spot checking of a variety of food crops about the country were done in 1957 and 1958 by Dr. Kulp's group at Columbia Uni-

versity. The sample highest in Sr^{90} which we have analyzed, however, were of wheat submitted to us by the State of Minnesota.

Meanwhile the USPHS on its own initiative has since 1957 established and expanded a milk sampling network across the country. Milk and milk products are the prime source of calcium in our diet. Inasmuch as Sr^{90} follows the calcium around in the food chain and into our bones, the Sr^{90} content of milk is the best index of Sr^{90} intake and hence the best index of the amount of Sr^{90} which may be deposited in the human skeleton.

In other words, the amount of Sr^{90} in milk is a good indication of the current hazard of Sr^{90}, and it is therefore appropriate to use milk Sr^{90} for surveillance purposes in this country. This should not imply in any way that milk is especially hazardous. In fact, milk is clearly one of the most favorable sources of calcium from the standpoint of the strontium 90 problem.

Representative HOLIFIELD. At that point may I ask you if you believe that we have an adequate program for the sampling of milk throughout the country to keep us informed adequately on this subject?

Dr. DUNHAM. I think the program that we have at the present time is reasonably adequate. I think it should be expanded to a certain extent. It is a program—and I am sure that Dr. Weber or Dr. Terrill will give you more information on the Public Health Service program—which reaches across the country. There probably should be some sampling at more different latitudes than at present.

Representative HOLIFIELD. Would that same thinking apply to other food products such as vegetables and wheat?

Dr. DUNHAM. There is no end what one can sample. The problem is to do a job which will meet the needs of the situation from the health standpoint, and is still something that can be done. As I plan to point out, there is a real problem in getting competent people to do the analysis.

We are planning, and have made arrangements actually, to sample wheat from 17 major wheat producing areas just to get a broader picture. My hunch is we won't learn a great deal more than we learned from those very interesting samples which were submitted to us from Minnesota.

Representative HOLIFIELD. What is the nature of your training program to prepared qualified people to participate in as large a program as is necessary?

Dr. DUNHAM. We do not have a fellowship program in the Atomic Energy Commission in the basic sciences. We have not had one, as you know, for many years. What we have tried to do, then, is to train people in our own health and safety laboratory. We have trained scientists from this country and from other countries. We have coordinated and cooperated in terms of the actual techniques with the group at the Taft Laboratories of the Public Health Service.

As long as radiochemistry analysis for Sr^{90} is an expensive and as difficult a task as it is today, we will never have enough sampling and analysis to answer everybody's questions. I am sure we would all like to know the exact Sr^{90} content of each item of our diet. I understand that each year several million samples of milk are analyzed for bacterial count. To do the same for fallout would cost several hundred

million dollars per year, provided one could find and train enough radiochemists for the job.

Fortunately an occasional item in the diet relatively high in Sr–90 carries none of the dire consequences of a batch of milk contaminated with hemolytic streptococci or tubercle or diphtheria bacilli. It is the average Sr–90 intake over the year which will be reflected in the bone, not the peak values nor the lowest values. With all the milk sampling locations averaging well under 30 uuc Sr–90/liter to date it is unlikely that in the United States the average level of radiation to the bone from Sr–90 from weapons tests detonated to date will equal the seal level "natural background" exposure.

Representative HOLIFIELD. At this point I am going to ask you again what is a micromicrocurie?

Dr. DUNHAM. That is a millionth of a millionth of a curie.

I am furnishing for the record a tabulation entitled, "Sampling Systems Related to Radioactive Fallout." It is interleafed here in the following page.

(The material referred to faces this page.)

Dr. DUNHAM. The Atomic Energy Commission's experimental and laboratory research in biology and medicine related to the problem of fallout falls naturally into two major categories: first the movement of fallout into and in the food chain and water supplies, once it has been deposited on the earth's surface, and, in addition, the matter of absorption by man from food, water, or air and the deposition and ultimate fate of different isotopes in the human body.

Second is the work aimed at quantitating the effects of ionizing radiation on the human body and on human germ cells in order to gain a more precise knowledge of the hazards of fallout in terms of human suffering.

The AEC-supported work on soil chemistry and movement of strontium 90, cesium 137, and other nuclides from soils and plants into the food chain is comprised of the following projects:

Title: Collection and Preparation of Soils, Plants, and Animals for Calcium and Strontium Analyses.
U.S. Department of Agriculture, $48,892; L. T. Alexander.

Title: Equipment and Methods for Decontamination of Agricultural Lands Contaminated by Radioactive Fallout.
U.S. Department of Agriculture, $25,000; Walter C. Hulburt.

Title: Accumulation and Movement of Fission Products in Soils and Plants.
U.S. Department of Agriculture, $90,000: R. F. Reitemeier.

Title: Utilization of Phosphorus From Biological Material and Uptake of Strontium by Various Type Crops.
University of Arizona, $6,500; W. H. Fuller.

Title: Study of the Internal or Metabolic Factors and the External or Environmental Factors Affecting Ion Absorption by Plants.
University of California, $13,831; Louis Jacobson and Roy Overstreet.

Title: An Investigation into the Utility of Radiation Sterilized Soil as a Medium for Growth of Plants and Micro-organisms.
University of California, $12,898; A. D. McLaren.

Title: Study of the Decontamination of Soils Containing Radioactive Elements and Salts.
University of California, $22,781; Roy Overstreet.

Title: Study of the Behavior of Certain Chelating Agents in Biological and Soil Systems.
University of California at Los Angeles, $10,705; Arthur Wallace.

Title: Distribution of Nuclear Fallout.
Columbia University, $113,554; J. L. Kulp.

Samples Drawn from:	Sampling system	Samples Collected by:	Samples Analysed by:	Number of Stations
Upper-air	Project Ash Can	AF Hq Com	Contractor	2
"	Experimental sampling (GMI,CML,Del,110th RAG,etc)	Contractors	Contractor	2
"	Research sampling	AFCRC	AFCRC	Variabl
Surface air	National Surveillance Net	USPHS	USPHS	44
"	80 Meridian Net	USNRL	USNRL	21
"	AEC Site Net	Contractor	Contractor	11
"	Research & Development (AMF, Scripps,ANL,UCLA)	Contractors	Contractors	3
		AFCRC	AFCRC	1
"	Carbon dioxide sampling	USWB	Contractor	5-10
Deposition	Gummed film Net	HASL	HASL	197
"	Pot & funnel Net	HASL	HASL,contractor	67
"	"Washtub" Program	Contractor	Contractor	5
"	National Surveillance Net	USPHS	USPHS	44
"	80th Meridian Net	AFCRC	AFCRC	6
"	U.S. Soil Program	HASL	HASL	17
"	Foreign Soil Program	USDA	HASL	60
"	Tritium projects	Contractors	Contractors	3
"	Research sampling (Wt Wash.,BNL,MIT,U OF MICH. UCLA)	Contractors	Various	5
Biosphere	Ocean Sampling	Contractors	Contractors	10-15
"	Tap water	HASL	HASL	2
"	HASL Pasture Program (Soil,Vegetation, Animal bone)	USDA	HASL	6
"	Chicago Pasture Survey (Soil, vegetation)	USDA	HASL	8
"	Los Alamos C^{14} Program	Contractor	Contractor	50
"	Food sampling	HASL & Contr.	HASL	Variable
"	HASL Milk Program	HASL	HASL	4
"	Los Alamos Milk Program	Contractor	Contractor	67
"	Lamont Milk Program	Contractor	Contractor	30
"	HASL Background Survey		HASL	400
"	Research projects	Contractors	Contractors	
Man	Lamont Human Bone Program	Contractor	Contractor	30
"	Urine	HASL	HASL	Variable
"	Whole Body Counting		Contractor	2

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UNITED STATES ATOMIC ENERGY COMMISSION

SAMPLING SYSTEMS RELATED TO

	Number of Stations	Frequency of Sampling	Year Established	Radiation Analysis: Gross Radiation	Radiation Analysis: Fission Products
cor	2	4 per mo.	1956	β	Sr^{90},Sr^{89},Zr^{95},Cs^{137},Ba^{140},Ce^{144}
tor	2	Irregular	1953	β	Sr^{90},Sr^{89},Zr^{95},Cs^{137},Ba^{140},Ce^{144}
	Variable	Irregular		β	Sr^{90},Sr^{89},Ba^{140},Ce^{141},Ce^{144}
	44	Daily	1956	β	
	21	Daily	1956	β	
		Monthly			Sr^{90},Sr^{89},Y^{91},Cs^{137},Ce^{141},Ce^{144}
or	11	Daily	1953	β,γ	
ors	3	Irregular		β	Sr^{90}, various others
	1	Daily	1958		Sr^{90}, various others
or	5-10	Few per yr.	1958		
	197	dup.Daily	1951	β, est. γ	est. Sr^{90}
tractor	67	Monthly	1954	β	Sr^{90},Sr^{89}
or	5	Each rain	1955	β	Sr^{90},Sr^{89},Ba^{140},(Cs^{137} New Zealand only)
	44	Daily	1956	β	
	6	Bi-weekly	1956		Sr^{90}, various others
	17	dup. Annual	1955		Sr^{90}
	60	dup. 2-yr.	1955		Sr^{90}
ors	3	Each rain	1958		
	5	Various		β	Sr^{90}, various others
ors	10-15	Wkly to Quarterly	1948		Sr^{90} various
	2	Monthly	1953		Sr^{90}
	6	dup Annual	1955		Sr^{90}
	8	dup Annual	1953		
or	50	1-3 yrs	1956		
	Variable	Total 150/yr	1957		Sr^{90}
	4	Monthly	1954		Sr^{90}
or	67	Wkly to Quarterly	1956		Cs^{137},Ba^{140}-La^{140}, some Sr^{90}
or	30	Total 200/yr	1954		Sr^{90}
	400	Semi-annual	1957	γ	
yrs					Sr^{90},I^{131}, others
or	30	Total 1500/yr	1954		Sr^{90}
	Variable	Total 30/yr	1954		Sr^{90}
or	2	Some wkly	1956	γ	Cs^{137}

DIVISION OF BIOLOGY AND MEDICINE

ED TO RADIOACTIVE FALLOUT

	Tracers	Natural Activities	Supplementary analysis
	Rh^{102},W^{185}		
	Rh^{102},W^{185}	H^3,C^{14}	Particle size, ozone
	Rh^{102},W^{181}	H^3,C^{14},Pb^{210}	Particle size, total mass, chemistry, humidity
	W^{185}	Pb^{210}	
	Rh^{102},W^{181}	C^{14},Rn^{222}	Particle size
		C^{14}	
	W^{185}		
nd only)	W^{185} (except N.Z.)		Solubility
	Rh^{102},W^{181}	H^3,Pb^{210}	
		H^3	
	Various	Various	Natural salts, radar cloud data, snow crystal structure, drop size, etc.
	W^{185},Co^{60},Zr^{95}	C^{14}	Various chemical & biological data
			Stable Ca
		C^{14}	C^{12},C^{13}
			Stable Ca
			Stable Ca
		K^{40}	Stable K
			Stable Ca
			Stable Ca
		Ra^{226},K^{40}	

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Title: Ion Interactions in Plant Tissues.
University of Connecticut, $5,000; Fred H. Emmert.
Title: Material Transfer Between Plants Through Adjacent Root Systems.
Dartmouth College, $7,756; F. H. Bormann.
Title: The Path of Radial Movement of Minerals From Soil to Xylem.
Duke University, $3,853; Paul J. Kramer.
Title: Plant Biochemistry of Boron.
Iowa State College, $8,470; Samuel Aronoff.
Title: The Absorption and Utilization of Radioactive Nuclides Applied to Above-Ground Plant Parts.
Michigan State University, $26,000; H. B. Tukey.
Title: The Mechanism of Active Absorption of Radioisotopes by Plant Cells.
University of Missouri, $3,460; Jacob Levitt.
Title: the Relations of Fallout and Other Factors to Soil and Plant Contamination and the Assimilation of Fission Products and Other Factors by Range Livestock.
University of Nevada, $45,000; V. R. Bohman and C. Blincoe.
Title: The Mineral Composition of Plants Grown on Southeastern Soils as Related to Soil Characteristics, Lime and Fertilizer Additions, and Root Distributions with Particular Emphasis on Strontium 90.
North Carolina State College, $12,528; N. T. Coleman.
Title: Detailed Characteristics of Soil and Vegetation on Selected Sites To Serve as Basis for Future Evaluations of Effects of Radioactive Contamination.
Ohio State University, $28,794; Nicholas Holowaychuk.
Title: The Effects of Soil Temperature and Morphological Age of Plants on the Uptake and Assimiliation of Radioactive Phosphorous.
Oregon State College, $7,945; S. B. Apple, Jr.
Title: Relationship of Soil Properties to Chemical Reactions and Other Phenomena Involving Sulfur.
Oregon State College, $7,000; Moyle M. Harwand.
Title: Radioactive Iron Studies With Soils and Crops of Puerto Rico.
University of Puerto Rico, $3,700; J. A. Bonnet.
Title: Research Concerning the Accumulation of Radioactivity by Plants.
University of South Carolina, $4,602; W. T. Batson.
Title: An Ecological Study of the Vascular Shore Plants of the PAR Reservoir. Savannah River Plant.
University of South Carolina, $8,756; Wm. R. Kelley.
Title: Metabolism of Selenium and Sulfur in Plants.
South Dakota State College, $4,320; E. I. Whitehead.
Title: Vegetation Studies Related to Movement of Radioactive Wastes.
University of Tennessee, $21,986; Royal E. Shanks.
Title: Use of Radioisotopes in Studying Lime-Induced Chlorosis.
Utah State University, $8,500; R. L. Smith and H. H. Wiebe.
Title: The Chemical Characteristics and Physiological Effects of Selenium.
University of Wyoming, $9,500; Irene Rosenfield, O. A. Beath, and H. F. Eppson.
Title: Environmental Radiation.
University of California at Los Angeles, $165,644; Kermit H. Larson.
Title: Absorption of Radioelements into Plants.
Hanford Atomic Products Operation, $66,000; F. P. Hungate.
Title: Waste Disposal.
Los Alamos Scientific Laboratory, $31,000; C. W. Christenson.
Title: Ecological Research.
Oak Ridge National Laboratory, $225,000; E. G. Struxness and S. I. Auerbach.

I shall enter for the record, as appendix B to my statement, a summary of each of those projects.

(The material referred to appears on p. 62.)

Dr. DUNHAM. The AEC-sponsored and United Kingdom soil and pasture studies have established the following facts:

1. One can count on no important discrimination against strontium 90 by present varieties of food crops.

2. Much of the strontium 90 now in food got there not via the soil, but by falling out directly on growing crops, especially if fallout occurred near harvest time.

3. The levels of strontium 90 fluctuate month to month, season to season, but soil levels and bone levels have risen slowly and steadily.

4. There is evidence for some slow fixation of strontium 90 in some soils.

5. Strontium 90 is slowly moving downward in unplowed soil.

6. The addition of quantities of lime and the like to acid soils would at most reduce by one-half the strontium 90 uptake in crops grown on such a soil.

Our studies of the toxicity of radioisotopes internally deposited in humans and in experimental animals have increased in scope and added new knowledge. It should be noted that the International Commission on Radiological Protection, largely as a result of work done under AEC auspices and corroborated in other countries, has raised the maximum permissible body burden for industrial workers from 1 μc to 2 μc, while for the first time taking cognizance of exposure to the total population it has used a factor of one-thirtieth instead of one-tenth in arriving at a new suggested permissible level for the total population of 0.066 μc.

Representative HOLIFIELD. I think there should be some comment as to the difference that is involved between the two committees at this point it being one-thirtieth instead of one-tenth, and the significance of that and the reason why this difference does exist between the National Committee on Radiation Protection and Measurements and the International Commission on Radiological Protection. This has received quite a bit of newspaper publicity.

Dr. DUNHAM. I know you are going to get a full statement from both Dr. Taylor and Dr. Failla, but I think I can summarize it briefly, sir. Both committees agree on the basic figure for industrial workers. Both committees agree on the basic figure for individuals living in the environment of an atomic energy or radiation producing establishment.

The International Commission suggested a figure for the population as a whole for internal emitters such as strontium 90, which is taken up in a one particular organ system They used a factor of 30. They also suggested a factor of 100 for isotopes such as cesium 137 with genetic effects. The national committee has a group studying what sort of recommendations it would like to make or would make with respect to the population as a whole and this committee has not yet finished its deliberations, though I believe a representative of that committee will be testifying later in the week.

Representative HOLIFIELD. Dr. Crow will testify in detail on that?

Dr. DUNHAM. Yes, sir.

Representative HOLIFIELD. Would you quickly convert the one-thirtieth and one-tenth into strontium units. One-thirtieth—wait a minute—one-tenth is now 200 strontium units, and one-thirtieth is 66 strontium units.

I think we will go into that in detail later but I wanted the record to show the meaning at this point.

Dr. DUNHAM. Yes, sir. At this point I would like to direct your attention to a number of appendixes to this statement dealing with

our research program. I will not detail these because I am running over my time. They are:

Appendix C: The atomic energy program in oceanography and marine biology (p. 71).

Dr. I. E. Wallen, of our Environmental Sciences Branch, prepared Appendix C.

Appendix D: Radiation-induced life shortening (p. 85).

Appendix E: Radiation genetics (p. 102).

Dr. Douglas Grahn, of our Biology Branch, prepared Appendixes D and E.

One of the most important statements is that prepared by Dr. Leroy Augenstine, also from our Biology Branch, on our research in molecular biology which I submit as appendix F (p. 123).

Appendix G: Current status of the internal emitter program (p. 138).

Dr. John F. Bonner, of our Medical Branch, prepared this appendix.

Appendix H: Ecological aspects (p. 144).

This was prepared by John N. Wolfe, our Division.

Appendixes I and J: The first of these two is entitled "The Status of Bone Marrow Therapy," by Dr. H. D. Bruner; the second, "Status of Antiradiation Projects," is also by Dr. Bruner (pp. 147 and 152).

Dr. DUNHAM. This most fundamental work aimed at unraveling the mechanisms and the several steps involved in production of radiation injury at the molecular level offers some hope of shortcutting the tedious direct approach to the problem involving hundreds of thousands of animals. It may give us leads as to methods for forestalling or correcting radiation injury.

I would like to point out that the United Nations Scientific Committee on the Effects of Atomic Radiation has clearly recognized the importance of studies at the molecular and cellular level for further progress in radiation biology. At their most recent meeting the committee especially emphasized the importance of this approach to the critical evaluation of injury at the extremely small dose rates resulting from fallout. Their feeling was that studies at this level should have equal or greater promise than statistical experimentation involving large numbers of animals.

Thus, approximately $5 million or 14 percent of the current research support provided by the Division of Biology and Medicine deals in some way with the area of molecular biology. Details of this program are presented in appendix F to this statement (p. 123).

And now I should like to take up point by point the major unresolved questions as enumerated in your summary statement from the 1957 hearings.

"1. How clean can nuclear weapons actually be made? The solution to this question lies in the future of weapons development."

The committee is, I believe, conversant with what progress has been made in this direction to date. It does not need to be stressed at this point that an arsenal containing weapons with different amounts of radioactive byproducts for a given yield is an arsenal better equipped than one not containing such weapons.

"2. To what degree is the distribution of radioactive fallout uniform or irregular throughout the world? Vigorously conducted sampling programs will help to answer this question."

This question and a related one—whether or not our sampling programs have been sufficiently vigorous—are among the principal matters your committee will be exploring these next few days.

Measurements of fallout on the ground and of radioactivity in the troposphere and statosphere have made apparent some of the complexities of the true patterns of global transport and mixing, as contrasted with idealized models. Our knowledge about the distribution of weapons debris in the atmosphere has been greately improved by virtue of data coming from Defense Department programs, augmented by AEC "Ashcan" stratospheric balloon data for the upper atmosphere and by other AEC data for air, water, and soil at the earth's surface.

AEC and DOD upper atmosphere data have demonstrated in the tropical latitudes a well-defined drop in atmospheric radionuclide concentration as one passes from the stratosphere into the troposphere. These data also suggest strongly the lack of any prompt uniform mixing in the stratosphere, either horizontally from pole to pole or vertically. The reliability of the "Ashcan" data, though improving, is not yet sufficient to warrant their use alone with any great assurance, but as a supplement to the DOD data they are valuable and confirmatory.

Ont important prediction has been verified; namely, a substantial reservoir of longer lived fission products does indeed exist in the stratosphere. The exact inventory is still in some doubt. Various estimates based on measurements just prior to the U.S.S.R. October test series in 1958 range from a low of 0.6 to about 1.8 Mc strontium 90.

The information available about inputs of debris to the stratosphere is subject to large uncertainty. In addition to the knowledge of the total and fission energy yields of weapon explosions (ours and those of other countries) it is necessary to know whether they were land, water, or air bursts. Even then it is difficult to estimate the fractions of the debris produced that come out as (1) "local fallout" (near the site of detonation, relatively speaking), (2) tropospheric fallout (around the world, perhaps, possibly in a "band"), and as (3) stratospheric fallout (worldwide). This information is obtainable only from actual measurement taken on some of our shots at the time of testing. Unfortunately these measurements may or may not be applicable to other shots under differing test conditions.

From a hazards point of view, stratospheric inventory estimates based on measurements in the stratosphere are important because these estimates can be combined with other information (on input rates and fallout rates) to give estimates of residence times of radioactive strontium 90 (or other debris) in the stratosphere. Such residence time estimates are important because predictions of future consequences of testing or of nuclear war or other injections of debris into the stratosphere actually depend in large part upon what is assumed about residence time.

The concept of stratospheric residence time as being a single figure applicable to all stratospheric debris has had to be modified. The first large injections of debris in 1952 and 1954 were placed high in the equatorial stratosphere. Here the vertical exchange of air is said by meteorologists to be especially slow, because of the intensity of the

stratospheric temperature inversion. Seasonal rearrangements of the atmospheric circulation are also at a minimum near the Equator.

Many subsequent high-yield tests have had preponderantly lower mushroom clouds. During the past year a number of tests have been made north of the Arctic Circle. In this latter part of the stratosphere it appears that vertical mixing and entry into the lower atmosphere are more rapid, particularly in winter and early spring. There is growing evidence that a major part of the debris from such high-altitude tests may fall out within the first year, or perhaps even within the first spring. In this length of time the debris is still largely concentrated in the poleward half of the Northern Hemisphere. The "residence time" will then be constantly changing as the global distribution changes.

Such meteorological sophistication as already exists suggests that regardless of other factors the residence time estimate for a given batch of new debris will depend upon the place (altitude) where the debris is put into the stratosphere. Evidence tending to support this view comes not only from stratospheric measurements but from isotope ratio measurements in surface rainwater.

Differences in the rates of fallout and the rates of worldwide spread between equatorial and polar tests are now appearing as the debris from our Operation Hardtack of last summer, tagged with tungsten 185, and the fresh debris from the heavy U.S.S.R. series of last October are being sampled and measured. Unfortunately, another 6 months or so must elapse before data can be reasonably expected to fall into an interpretable pattern.

The well-established fact that stratosphere is not to be pictured as simply on the other side of a membrane from the troposphere tends to complicate material balance estimates for strontium 90. In the polar regions one who ascends in the atmosphere vertically finds himself in the stratosphere at a much lower altitude than if he were to ascend in the Tropics. Furthermore, in the middle latitudes so-called double tropopauses occur, where the higher tropical overlaps the lower polartropopause. These overlaps, or breaks, are thought by some to provide an opportunity for horizontal movements of air out of the stratosphere.

Representative HOLIFIELD. We are going into this this afternoon at some length with Dr. Machta and his group on weather phenomena?

Dr. DUNHAM. Yes, sir.

Representative HOLIFIELD. I hesitate to take the time now, but if you have someone with you that could draw on the board there a replica of the globe and what this means, while you continue with your testimony, I think it might be illustrative of this very important point, and as this point is developed in the afternoon hearings it is going to have a significant meaning of the difference between the tests that are held near the Equator by the United States and the United Kingdom and the tests which are held in the northern latitudes by the Soviets.

This is a very important scientific information and it will be gone into at some length. If you can't find the chalk we will just omit it at this time.

Representative PRICE. May I ask a question at this point?

Would you elaborate a little on tungsten 185?

Dr. DUNHAM. It is a material produced as a radioactive material in some of the weapon detonations in the Hardtack series. We are able to use it as a tracer to distinguish the fallout and transport of materials from those tests from some of the other tests which took place during the last year.

Representative PRICE. What is the half life of it?

Dr. DUNHAM. I think it is about 55 days.

I have been informed by Dr. Libby it is 74 days.

Representative PRICE. Does it cause any additional concern in the fallout problem?

Dr. DUNHAM. The best information we have—a good deal of work was done on it a number of years ago at Berkeley—is that it is practically not at all absorbed into the human body.

This is Mr. Holland, Mr. Holifield. Mr. Holland is a meteorologist on the staff of the Division of Biology and Medicine.

Representative HOLIFIELD. Without going into great detail, Mr. Holland, will you place on the half-cut of the globe the approximate position of the Pacific tests and the Christmas Island tests and also the Soviet tests and explain the significance of the different locations on the globe for the benefit of the audience?

Mr. Holland. Sir, the Christmas Island tests are very close to the Equator. Our Pacific tests are about 10° north. Our Nevada tests are about 40° north. The Russian Siberian tests are about 51°, and Arctic tests about 73°.

Representative VAN ZANDT. What are the last tests?

Mr. HOLLAND. The Soviet Arctic tests.

Dr. DUNHAM. Beyond the Arctic Circle.

Mr. HOLLAND. I have drawn an exaggerated vertical scale here. This line which is the tropopause separates the lower portion of the atmosphere from the stratosphere. In the equatorial region it is about 55,000 feet high. In the polar regions it varies from about 30,000 to 40,000 feet and sometimes lower than 30,000 feet.

In the middle latitudes there are usually two tropopauses. They don't tend to run smoothly into one another. So there is an opportunity for stratospheric air to move horizontally into the troposphere.

Representative HOLIFIELD. Because of the location of the Soviet test and because of the lowered ceiling of the troposphere, the puncture of a troposphere by a megaton test is easier and quicker and then because of the peculiar disjointed banding there, as evidenced by your chart and the turbulence which intervenes between the two levels of the troposphere it means that the Soviet debris comes down much quicker, does it not, than the debris from the United Kingdom and the U.S. tests, which has a higher troposphere, and also is not faced with the same area of turbulence immediate?

Mr. HOLLAND. Yes, sir; that is substantially correct. There are several reasons. First of all, there is somewhat more exchange between the stratosphere and the troposphere at high latitudes. There is this possibility of horizontal exchange in the middle latitudes and possibly a larger fraction of the Soviet debris is put into the stratosphere in the first place.

Representative HOLIFIELD. Is there anything in the time of year, and if so, why?

Mr. HOLLAND. I have purposely drawn this somewhat asymmetrical as if it were winter in the Northern Hemisphere and summer in the Southern Hemisphere. I could exaggerate this somewhat more. The equatorial conditions extend to higher latitudes in the summer. The polar conditions extend to lower latitudes in the winter. Actually, the exchange process is more active in the winter and early spring and mixing within the polar stratosphere is much more active within the winter.

Representative HOLIFIELD. I think this gives the fundamentals of this situation.

Senator PASTORE. May I ask a question at this point, Mr. Chairman?

How about the density of the Arctic shots as against the equatorial shots. Is there more of a tendency to remain dense even though it comes down quicker? Does it remain dense in a particular area with a less likelihood of spreading out as against the other shots?

Mr. HOLLAND. Yes, sir; that is correct. Since the material comes out of the stratosphere more rapidly it has not had as much chance to spread out over the world and therefore it comes down in higher concentrations.

Senator PASTORE. In other words, the equatorial shots have more of a tendency of spreading over a greater area of the earth's surface?

Mr. HOLLAND. This is the way it looks.

Representative VAN ZANDT. Coming down in the atmosphere, what effect does the jetstream have on the input of the material?

Mr. HOLLAND. The jetstream is located in the middle latitudes at the top of the troposphere, somewhere around the polar tropopause. It is an area of extremely strong wind and turbulence. Turbulence has been observed above the jetstream for many thousands of feet. It is believed in the vicinity of the jetstream region there is more active mixing possibly both vertically and horizontally than elsewhere in the atmosphere.

Representative HOLIFIELD. Thank you very much, Doctor.

Now, will you proceed, Dr. Dunham?

Dr. DUNHAM. From a global standpoint the information on fallout rates and accumulations, at the earth's surface, are improving, though still far from perfect.

Regardless of the actual pattern or amount or residence time of debris in the stratosphere, it can be stated that the debris does not fall out uniformly on the earth's surface. Strongly defined north-south irregularities in profile exist as will be discussed later in these hearings.

For prediction and hazards estimate purposes, it is important to be able to partition the observed north-south fallout profiles into components representing stratospheric and tropospheric fallout respectively. Since some weapons have been fired which yielded only tropospheric debris, it should in principle be easier to study these shots and arrive at an understanding about tropospheric debris "trajectories." Then one can estimate the location and amount of worldwide tropospheric fallout and substract from the total to obtain an estimate of the location and amount of stratospheric fallout.

Unfortunately, our knowledge about the tropospheric fallout from small shots is limited, and the applicability of this knowledge to tropospheric fallout from large yield shots is even more limited. One must keep in mind that tropospheric fallout is to be thought of in terms

of masses of debris distributed vertically and horizontally in the lower atmosphere (where the weather is), and presumably subject to (1) spreading and mixing, and (2) wanderings about as they are buffeted by the winds.

Inasmuch as the wind almost never blows precisely from west to east, tropospheric fallout does not make an even band about the globe. Weather trajectories of debris from both Pacific and Nevada shots strongly support this idea. Indeed tropospheric winds at the Pacific test site tend to blow in nearly opposite directions at different altitudes.

It should be apparent from the discussion up to this point that one must expect to find in different places different amounts and rates of fallout, reflecting the global variations in stratospheric and tropospheric transfer and the variations in locatoin of tropospheric debris. One must further take into account weather as a determining factor in places where debris may fall out.

At the hearings 2 years ago little emphasis was given to the type situation which may have produced relatively high concentrations of strontium 90 in milk and wheat in the northern plains States in the summer of 1957. I am talking about something intermediate between the strictly local Nevada fallout and the tropospheric long-range fallout, something analagous to the "rainout" over Troy, N.Y., in 1953. The milk and grain contamination subsided during the summer of 1958, while the soil contamination continued to increase. From this it may be deduced that an appreciable part of the strontium 90 in the whole grain or on the fodder was received directly from air and rain instead of being taken up from the soil.

To complete the picture, we have still to contend with local conditions which may produce variability in measurements. It is unreasonable to expect a forest to behave like a meadow, or a mountaintop like a valley as repositories of fallout. Cyclonic and orographic rainfall will behave differently as scavengers. Soil samples cannot be expected to have the same amounts of strontium 90 as rainwater collections or collections on gum paper.

As further experimental data are obtained some of the puzzles will undoubtedly be solved, but new ones may well arise. There is no reason to expect the global atmospheric circulation to behave in a simple manner.

From a hazards point of view one will want to determine first an overall population hazard and hence one will want some sort of population-weighted average fallout level. But one also will want to look for "hot spots." By what has been said, it should be apparent that regions of relatively high concentration can result from a variety of circumstances and will not be apparent unless sought out.

Representative HOLIFIELD. If you will pause at that point, I will ask you to explain the characteristics or implications of the so-called hot spots or hot areas, such as those that have proven to be in Minnesota and North Dakota, and the St. Louis milk shed, my colleague from St. Louis suggests. Also, whether in your opinion this is stratospheric deposit or whether the Nevada tests contributed to it.

Dr. DUNHAM. First, I would like to define the words "hot spot." As I first encountered it, it was a word coined by Dr. Kermit Larsen, who has done many of the studies in the vicinity of the Nevada test

site. When he talks about a hot spot, he is talking about an area of a number of acres. He is not talking about whole counties or whole States in which the radioactivity, fresh fallout, is manifold that a short distance away. What we are talking about here is areas, county, several States size, which in most instances we believe are the result of rainouts occurring in trajectories from weapons detonated at our Nevada test site. As you know, the first example actually occurred not from Nevada, but from Alamagordo with the rainout which was discovered later by getting into the paper for Kodak film near Vincennes, Ind. These levels are not severalfold in terms of strontium 90 or cesium adjacent areas, but they may be as much as half again to two or three times. The important thing to bear in mind—and this was borne out very clearly by these observations on the wheat, and also we have similar information from our pasture program—is that if the level is high 1 year, particularly if rain occurs just before harvest, you can actually soak strontium 90 into the hull or germ of the wheat though not as much will get into the white flour as the wheat is milled, that this does not mean that next year you will have the same trouble, and you will have this building up and up and up as occurs in accumulation of strontimu 90 in the soil.

As Dr. Reitemeier and Dr. Alexander have noted in these pasture programs, the buildup in the soil has been generally a fairly steady proposition, and the buildup in the animal bones that fed on this pastureland. But the amounts of strontium 90 in the fodder has varied tremendously. It means that there has been deposited on the fodder, the fodder is either eaten or harvested and put into the silo, and it never gets into the soil. So it cannot get back into the food chain in that way again. It is one way to decontaminate a very dense field, that is, to actually harvest the field before the stuff gets washed down into the soil.

Senator PASTORE. Is research possible to detect the source of the strontium 90 with relation to that which was deposited in Minnesota and North Dakota and in St. Louis?

In other words, to be more specific, did this come from Nevada? Can it be determined whether it did? Did it come from the Arctic shots? Can it be determined whether it did? Did it come from the Pacific shots, and can it be determined whether it did?

Dr. DUNHAM. I think one can state categorically it did not come from the Pacific shots, because there were none in the summer of 1957. That was the summer and spring when we had a big series, Operation Plumbob in Nevada. We have gone back and Dr. Dunning is here if you wish him to comment on it, and followed the trajectories from certain of the devices detonated in Nevada, and also checking through the Weather Bureau we have found that one or two of the trajectories, not the little one kiloton shots, actually went in that general direction, and at the time they are estimated to have arrived over North Dakota and Minnesota, there was a heavy rain. I think there is very little question but what the Mandan milk and the Minnesota wheat, those levels were the result of material from our Nevada Proving Ground.

Mr. RAMEY. Are the strontium levels through those areas and soil levels also higher than other parts?

Dr. DUNHAM. The last figure I have for strontium 90 in the soil in the Mandan area is in the forties. There are higher levels farther

south. It is possible that it may have been that the material was dropped so that not as much got in the soil. They are not unusually high, the soil levels.

Mr. RAMEY. I believe Dr. Machta, who will testify this afternoon, believes that it is not just the Nevada tests that are making the contribution to the higher levels.

Dr. DUNHAM. That is absolutely correct, but I think these big jumps, where you almost made double or even triple the amount, are probably largely and have been at least in the past due to Nevada. This material coming down from the north polar tests is coming down with storms and rain, so there is bound to be unevenness.

Representative VAN ZANDT. Doctor, in reply to the question the Senator from Rhode Island asked you, you indicated that it was possible to trace the source of the material that was deposited over North Dakota and Minnesota to the Nevada test. Could you trace the source of the material if it were held in the Arctic? I am thinking of the distance involved here.

Dr. DUNHAM. Actually, Dr. Libby and others who are collecting pot samples and analyzing them can, on the basis of the time that these detonations occurred in the Arctic, pretty well identify material from these Arctic shots. As I indicated before, we have the tungsten to help us identify material from our shots last summer.

Mr. RAMEY. Then the answer to the Senator from Rhode Island's question is yes, you can trace the source of the material regardless of where it takes place throughout the world.

Dr. DUNHAM. That is correct.

Senator PASTORE. That is, we can trace our own because we put an isotope in, I suppose, to detect it later on. By the process of elimination, you could do that, too, by saying it is not our own. You would have to say it would have to be either the Great Britain or the Soviet Union.

Dr. DUNHAM. I think we have enough information on when various countries did any major testing so that by taking the so-called strontium 89-strontium 90 ratio, which is a decay ratio, and those two isotopes decay at different rates, one can then identify material from the October series.

Senator PASTORE. Then is it fair for me to assume that insofar as the material that was deposited on the Northern Hemisphere, that principally it came from Nevada and that some might have come from the Arctic shots, but not from the Pacific. Is that your conclusion?

Dr. DUNHAM. No, sir. What has been deposited on the Northern Hemisphere came from all shots as far as the United States is concerned. Each one contributed something to it.

Senator PASTORE. Let us take Minnesota, then.

Dr. DUNHAM. I would say that the major amount of material deposited in Minnesota and the North Dakota general area there came from both our Nevada and our Pacific tests. I think this material which was handed out to you suggests why I can make that statement quite categorically. The testing in a big way by the Russians was only the last 2 years.

Representative BATES. Doctor, those figures that we have been given relative to the number of megatons that might be safely or desirably exploded per year, was that predicated upon a wide distribution of

strontium 90 or was it predicated upon the area of greatest density? For instance, the northern climate?

Dr. DUNHAM. Mr. Bates, those estimates which were made at the time of the last hearings on fallout were based on the pattern of testing as it existed up to that time. The biggest single factor which has come in to change things has been the recent heavy testing above the Arctic Circle, which implies that there will be much more material in the Northern Hemisphere and less distributed worldwide, and getting into the Southern Hemisphere and therefore essentially diluting it.

Representative BATES. So for these particular areas you would have to set the figure downward from what has been previously established.

Dr. DUNHAM. This could well be.

Representative HOLIFIELD. Proceed.

Dr. DUNHAM. "To what extent do the biological processes of plants, animals and human beings—under normal conditions—exhibit a preference for or 'discriminate' against strontium 90 and other potentially hazardous isotopes that are taken up into the human body?"

It is now evident on the basis of researches here and in England that we can count on no consistent discrimination against strontium 90 in the soil by plants. We know of none which has the remarkable capacity that some mollusks and diatoms have of being almost totally able to tell strontium from calcium. Mechanisms exist for strontium 90 and cesium 137 to bypass the soil either by direct uptake via the leaves or by uptake in the grass mat through the base of the stems and the researches by Scott Russell in England demonstrated that with the cereal grasses soluble strontium 90 salts are readily absorbed into the grain if sprayed on during the formative stage. Reduction in uptake of strontium 90 from soil by existing methods of treatment with simple chemicals—calcium or potassium—can result in only small effects, reduction at most, to one half. The mechanisms referred to above for bypassing the soil seem to account for the peaks in fluctuation in strontium 90 content of food from month to month and year to year as seen in milk and wheat. The valleys would seem to be more likely representative of the uptake from soil. The question still remaining is, of course, "are the peaks from stratospheric fallout that bypasses the soil or from the troposphere?" The Mandan milk reached a peak value of 33 strontium units in the summer of 1957. It is suggested that a relatively heavy rainout of troposheric fallout from our own 1957 Nevada tests, not stratospheric fallout, was responsible for this peak.

"4. Is there a 'safe' minimum level of radiation or 'threshold' below which there is no increase in the incidence of such somatic (nongenetic) conditions as leukemia or bone cancer, or no decrease in life expectancy, in a population, resulting from radiation? The answer to this question appears difficult to find experimentally."

The last sentence must be underlined. While there is no new evidence clearly pointing to linearity of effect regardless of dose rate, no conclusive evidence pointing to a true threshold has been found. It now appears that there may be a series of curves, one for each of a number of situations involving a given dose rate and dose schedule, i.e., the matter of divided doses as incurred with diagnostic X-rays as opposed to the more uniformly incurred exposures from fallout. All the data on internal emitters in humans and experimental animals

point to a sharp break in the curve for bone tumor formation well above any recommended permissible levels. In other words, even though a threshold may not exist, very few bone tumors will result from low body burdens of strontium 90. The data for radiation-induced leukemia in mice from internal emitters as will be brought out in later testimony are not so clear. The picture with respect to the life span effects from fallout is unchanged.

"5. What is the genetic 'doubling dose' of radiation to man? That is, what dose of radiation will cause the spontaneous genetic mutation (change) rate to double?"

While the statement no radiation exposure to the gonads without some genetic effect seems to still hold, the work of the Russells in Oak Ridge, and Carter in England clearly demonstrates a dose rate dependency for point mutations. Whether these new data mean that the true doubling dose for man or mice is the 40 roentgens taken by the U.N. Scientific Committee or is higher remains to be resolved. Certainly the new evidence would suggest the 40-roentgen figure is not too high for exposure incurred at very low dose rates.

"6. Should a distinction be made between absolute numbers of persons affected by fallout and percentages relating these numbers to the total population of the world, i.e., can we accept deleterious effects on a relatively small percentage of the world's population when the number of individuals affected might run into the hundreds of thousands? This question cannot be answered by considering scientific data only. Over all national policy and great moral issues are also involved."

I have touched on our studies of the complex relationships between the production of radioactive materials by nuclear explosions and resultant biological effects on humans. The question which accounts for most of our interest in these relationships today is, "How dangerous may fallout be?"

These hearings are designed to provide as satisfactory and up to date an estimate of the hazard as can be given. However, as was apparent in the hearings of 2 years ago, it is difficult to give such answers in terms which are directly meaningful to many persons.

As a substitute for labored efforts to describe the dangers of fallout in terms of estimated probabilities of various kinds of biological effects, together with explanations of the nature of such effects and of the conditions to which the estimates apply, we sometimes attempt to describe the dangers in terms of conditions or experiences with which the individual has some familiarity. For example, it has frequently been mentioned that the risk of any undesirable or serious biological effect or disease from fallout must be small compared to the natural risk of the same disease, because radiation doses due to fallout have been small compared to doses from natural sources of radiation. A variation to this approach has been to point out that the risk from fallout may be less than changes in risk from natural sources of radiation in moving one's residence from one location to another. All of these approaches to answering the question have their inherent limitations.

In my testimony before this subcommittee in the 1957 hearings I emphasized the fact that any exposure to radiation may be assumed to involve some degree of risk and is therefore undesirable unless

there is adequate reason for the exposure. On the other hand, we must conclude that, for sufficiently small doses of radiation, the risk may be too small to be of substantial concern. Nevertheless, as individuals we might be concerned about the effects of natural radiation and if we were convinced that the necessary effort were justified, we actually could reduce our exposure to radiation from natural sources by amounts larger than our present exposure to fallout.

Representative HOLIFIELD. At that point, I would like you to go back to the statement you made on the previous page, where you say that radiation doses due to fallout have been small compared to doses from natural sources of radiation, and give us some figures on that.

Dr. DUNHAM. The estimate of external dose to the body from fallout from weapons tests today, which your seminar group will come up with, will be less than a cumulative dose of one-tenth of a roentgen.

Representative HOLIFIELD. One-tenth of a roentgen?

Dr. DUNHAM. That is right, as compared with a lifetime dose of roughly 7 r. from natural sources of radiation.

Representative HOLIFIELD. Is that one-tenth of a roentgen or one-tenth of the natural radiation dose?

Dr. DUNHAM. It would be one-seventh of the natural if it is a total of one-tenth for a lifetime exposure. That is, one-tenth of an r.

Representative HOLIFIELD. Are the scientists agreed upon this figure?

Dr. DUNHAM. This group yesterday afternoon, I think, came to very close agreement on what this figure is. It is very similar to the estimate that the United Nations Scientific Committee made.

Representative HOLIFIELD. There will be testimony on this later?

Dr. DUNHAM. Yes.

Senator PASTORE. Doctor, may I ask you one question? From the standpoint of a scientist, this may not be a very sensible question, but I have a compulsion to ask it. Is there any such thing as building up an immunity in the human body as to the dosage?

Dr. DUNHAM. We have no evidence that this occurs, but I don't think this means that it can't happen. There are a few experiments which indicate that an animal which has survived a large dose of radiation is more resistant than had been expected. But generally, I think one can say that there is not a buildup of immunity or resistance to radiation.

Senator PASTORE. The reason why I asked the question is because you have developed a change of locale with reference to natural radiation.

Dr. DUNHAM. Yes, sir.

Senator PASTORE. Does that have any bearing on this question of immunity or building up immunity in the human body?

Dr. DUNHAM. We have no evidence that these people in areas of high-background activity are more or less resistant to radiation than the rest of the world. On the other hand, we are all hoping that studies can be made of these populations to get better information on what the true state is.

Senator PASTORE. In other words, you say that some effort is being made in that field of determining whether or not that case may be so?

Dr. DUNHAM. Very definitely we and the Public Health Service and other governments are planning studies, and some studies are al-

ready underway, of population groups which have been exposed for many generations or for many years, at least, to above average background levels.

These considerations led us to other questions, such as "What should we do about fallout," or "At what levels of radioactivity in the environment should we take positive measures to reduce exposures to radiation." Basically, these questions applied to fallout do not differ from the same questions applied to other risks of life. If we believe that the reasons for accepting any particular risk are sufficiently compelling, we accept them; if not, we choose an alternate course of action which avoids the risk. In doing so, we may either sacrifice a desired goal or substitute a more acceptable risk.

I have tried to state the principle in simple terms, but the application to actual cases may be far from simple. In a complex society, the individual is not always free to make a choice either on the basis of his own judgment or of his own desires. He may be effectively bound by judgments made and choices exercised by groups of which he is a member.

In general, the individual is dependent upon group discretion for the control of many environmental risks. Common examples are environmental santitation, purity of foods, and control of air pollution. In exercising such controls, appropriate agencies seek standards of protection which represent appropriate balances between the risks involved and reasons for acceptance of the risk.

Standards for the evaluation of risk from fallout which have most commonly been used in this country have been based upon the recommendations of such groups as the National Committee on Radiation Protection and Measurements, the International Commission on Radiological Protection, the National Academy of Sciences, and the Medical Research Council of the United Kingdom. Some of these recommendations relate directly to questions of hazards from fallout, while others provide useful guidance where applicable. Standards of radiation protection have been commonly described by such terms as maximum permissible dose and maximum permissible concentration. These terms are often misunderstand. A recommended maximum permissible dose is neither an absolutely safe dose nor is it a dangerous dose. It is a dose which in the judgment of the person or group of persons making the recommendation represents the greatest hazard that in their opinion should be permitted under conditions to which the recommendation is applicable. Under different conditions either a lower or a higher permissible dose may be more appropriate.

Representative VAN ZANDT. Going back to the standards that have been set by the various groups you have mentioned, has there always been a unanimous approval of the standards, or has there been a difference of opinion?

Dr. DUNHAM. The National Committee on Radiation Protection has worked since 1928 developing recommendations for protection against radiation. They have worked closely with the international group. I would say there has been a remarkable agreement as to what reasonable standards are.

Representative VAN ZANDT. Does that hold true as far as the Medical Research Council of the United Kingdom is concerned?

Dr. DUNHAM. So far as I know, there was no gross disagreement between any of these bodies. Their timing of when they made certain statements varied a little, one overlapping another. Generally they have moved always pretty much in harmony.

Representative VAN ZANDT. Then is it possible to say that the standards represent the unanimous opinion of the free world?

Dr. DUNHAM. I think this is correct. It would be even more than that because the U.N. Scientific Committee has representatives from the U.S.S.R. and Czechoslovakia, and there was at no time in their deliberations any questioning of the recommendations of the ICRP.

Representative HOLIFIELD. There is no intent on the part of this committee to magnify or minimize any of these figures. All we want to do is get the facts on the record. I appreciate the questions that my colleague has asked because we want the facts put on the record on these matters.

Representative PRICE. Doctor, would you say it represented a unanimous opinion or the best judgment of the majority?

Dr. DUNHAM. It is a considered opinion by people who have devoted a tremendous amount of their time and know-how to working on this problem. It is the best we can get.

Representative HOLIFIELD. When it comes to specific figures, there is a variance of opinion between scientists in degree.

Dr. DUNHAM. That is correct, sir.

Representative HOLIFIELD. It is not a large mathematical factor, but it is a matter of reasonably small degree. This is necessary in a field that is new and where the complete data is unknown.

Dr. DUNHAM. Certainly before World War II there was very little research in this area. It is a new field.

Representative PRICE. You could not reasonably expect unanimous agreement.

Dr. DUNHAM. No, sir. There would be something fishy about it if it were.

Representative HOLIFIELD. As a matter of fact, on all scientific experiments, isn't it true that there are variations of value judgment exercised by different scientists on all types of scientific experiments?

Dr. DUNHAM. This is very true, particularly in this area. There is no question about it.

Senator PASTORE. Doctor, may I ask a question on this very point? You say under different conditions, either a lower or higher permissible dose may be more appropriate.

Dr. DUNHAM. That is right.

Senator PASTORE. That leads me to this question: Hasn't the standard been approached rather cautiously by the scientific world?

Dr. DUNHAM. Yes.

Senator PASTORE. I mean haven't doubts been removed? While a higher dose may be permissible, there is no room left for a lower one. I am trying to get you to clear up this statement where you say under different conditions either a lower or higher permissible dose may be appropriate. You don't mean by that that the standard has been adopted that would permit a lower dosage to be injurious?

Dr. DUNHAM. If one admits, and I think we have to until proved conclusively otherwise, that any radiation exposure has some mathematically calculable, statistically harmful effect, then it becomes al-

ways a value judgment, as Mr. Holifield said, as to what effect, assuming the worst possible circumstances, you are willing to accept. That is what I mean when I say this. For instance, if there were a nuclear war, these standards that we are now living by would be relatively meaningless.

Senator PASTORE. That is to a higher dose. But how would it be as to the lower dose?

Dr. DUNHAM. If you set the standard even lower, then you reduce this very low probability of injury even more.

Senator PASTORE. In other words, what I am getting at is this. In order to allay the fears of the public, if such a fear does exist, I am trying to gage in proper perspective the quality of the standard that has been set. In other words, is it a standard that has been very carefully thought out with all the doubt resolved in favor of the human kind, or is it a doubt that then has been resolved in contemplation of what the world tension might be?

Dr. DUNHAM. I think it is the former. Particularly this is true of the new suggestion of the International Commission, which threw in a factor of 50 instead of the old factor of 10 for strontium 90. They could have kept the old factor of 10, I think, from the standpoint of the public as a whole. On the other hand, they felt that in view of the increasing use of radioactivity, whether we are talking about weapons tests or developing nuclear power and that sort of thing, that they should set a tsandard which they felt could absolutely be justified under any circumstances.

Representative BATES. Doctor, in view of your statement, I wonder if you would comment on the newspaper article this morning on this subject which reads as follows:

> Strontium does not have a genetic effect. It settles in the bone and can produce bone cancer and leukemia.

Dr. DUNHAM. This is essentially a correct statement insofar as the genetic part of it is concerned. There is essentially no dose to the germal cells from strontium 90 in the body. In experimental animals, there is no question but what sufficient amounts of strontium 90 in the bones will produce bone cancer and leukemia. This is essentially a correct statement.

Representatives BATES. Do you think that is consistent with your statement on page 34 in paragraph starting "While the statement no radiation exposure"?

Dr. DUNHAM. Yes, sir. I said exposure to the gonads. I think this is the source of confusion. That is, to the germ cells. The strontium 90 produces essentially no exposure to the germ cells and that is why it would not have a genetic effect.

Representative HOLIFIELD. Isn't it true that the gamma rays have the penetrating quality that would cause the damage to the genes and the chromosomes, while the deposit of calcium in the bone, the decay life is so slow and the range of the beta rays—or I mean from the strontium—is so short that there would be little likelihood of affecting the germ cells?

Dr. DUNHAM. That is correct.

Representative HOLIFIELD. But it would affect the bone cells and could cause cancer of the bone.

Dr. DUNHAM. That is right.

Representative HOLIFIELD. And lesions of that type.

Dr. DUNHAM. Yes, sir.

Currently recommended values of maximum permissible doses of radiation generally involve the cautious assumption that the hazard is proportional to the dose. To the extent that this is true, one may say, for example, that if the dose is permitted to reach two times the recommended maximum permissible value, the corresponding hazard is two times as high as was considered justifiable under the conditions for which the recommendation was made. How great a hazard this may be depends, of course, upon the magnitude of the hazard corresponding to the recommended maximum permissible dose. In this sense a maximum permissible value is similar to a speed limit. A speed equal to the speed limit is not an absolutely safe speed since many serious accidents occur at lower speeds. Nor is it extremely dangerous to drive at speeds somewhat greater than the speed limit. Neither the recommended maximum permissible dose nor a speed limit has any particular significance beyond marking the point at which an advisory group has agreed to draw the line in recommending a maximum degree of hazard appropriate under a given set of circumstances.

Representative HOLIFIELD. Your reference to this as a speed limit brings up the question of who is going to be the speed cop.

Dr. DUNHAM. That is very important. Even speed limits are set up on the basis of experience.

I would like at this point to emphasize the distinction between permissible doses of radiation to persons and maximum permissible concentrations of radioactivity in the environment. Our direct interest, of course, is in the radiation dose actually received by persons. Our best information on the uptake by humans of radioactivity from fallout in the environment is that being obtained by actual measurements in small children most nearly in equilibrium with their environment. On this basis we should within the next few years develop more realistic values than are now available for maximum permissible concentrations in the total food supply of radioisotopes resulting from fallout.

In principle, establishing the best possible value for a maximum permissible dose of radiation involves at least three independent evaluations: (1) estimating the total biological risk, (2) estimating the benefits to be gained from taking the risk, and (3) balancing the risk against the reason for taking the risk.

We have already discussed the uncertainties involved in estimating the biological risk. The uncertainties involved in estimating the benefits to be gained by taking the risk are probably much larger. But the most difficult step may be that of comparing biological risk to benefits which may be measured in economic or social gains. The problem is made more difficult by the fact that some or all of the benefits may not accrue to the person taking the risk.

In making the balance between risk and reason for acceptance some guidance may be drawn from everyday life. For example, in occupational standards, one criterion commonly used is that risks due to exposure to radiation should be small compared to other occupational risks. How small, of course, would depend upon the comparative ease of avoiding the risks. Reasons for acceptance of risk should not be confused with primary benefits to be derived from the activity from which the risk arises. These primary benefits

may be sufficiently large to far outweight any risks involved. In this case, the reasons for accepting a risk of any particular magnitude are to be found in the difficulties—in the form of time, personal inconvenience, expense, or other reason—involved in avoiding the risk.

It may be seen that the job of setting standards, even in the field of occupational health, is not a simple one. It is obvious that some of the members of any group charged with this responsibility will consider factors which others may not, or will weight them differently, depending upon their own experience and approach to the problem.

It is also obvious that standards of radiation protection, while based upon logical concepts, cannot be ideal. This is not, however, a condemnation of the standards nor of the system by which they are formulated. These imperfections are inherent in all of our solutions to the problems of life. In environmental health, radiation protection shares this difficulty with all other health standards. In the field of personal decisions whether we are confronted with the problem of buying a home, making a business decision or choosing a profession, our actions are inevitably based on imperfect knowledge of the consequences. The same is true of our actions in the field of international policy.

The important considerations are that—

(1) We bring to bear on the problem all of the information that can be made available;

(2) We take maximum advantage of the combined judgment of able and well-informed persons; and

(3) We, as a people, understand the general nature of the issues involved and the meaning of any standards which may be recommended and adopted.

Representative HOLIFIELD. Dr. Dunham, as chairman of the subcommittee, I want to compliment you on the statement which you have made, and the attitude which the AEC is taking toward the release of information on this very important subject, and also for the tables which you have presented to us which I know will be studied by the scientists of the whole world with a great deal of interest, because they are very significant.

Before we adjourn, we may have some questions, but I would like to summarize at this time, if I can, some of the points which I think you have made this morning.

In the first place, you have told this committee that the AEC has a substantial program of research into the effects of radiation from all sources, and that in the field of fallout the sampling and analysis of the soil and water and milk and bone content, you are spending about $3 million, or a little less than $3 million.

You have also revealed that the debris from the Soviet tests falls quicker from the stratosphere onto the earth's surface, and that it is dirtier because of the time element that exists between the explosion and its time of descent, the peculiar significance of the troposphere ceiling, and the location of the breaks in the troposphere band.

You have given us in this release here tables of fission yield from tests from the nuclear powers, which have a tremendous significance. It shows very clearly that in the period from 1945 to 1951 this was marked by the tests of small weapons, and that the fallout did not noticeably affect the world background radiation. That with the

introduction of the megaton—the million-ton weapon—in 1952 and 1954 and since then, they have done two things: They have multiplied the quantities of fission products being produced by approximately a thousand times, and they have put a significant fraction of this increased amount of fissionable material into the stratosphere, and that this brings about the worldwide hazard of global fallout which is tied to the megaton yield of weapons.

You have also brought out the fact that this fallout is not uniform. It is concentrated in the Temperate Zone where most of the rainfall occurs, and where most of the people live, and that in the Temperate Zone it is not completely uniform. It has hot spots in some areas and cooler spots, relatively speaking, in other areas.

Since these long-lived fission products are cumulative, the fact that a significant problem has been created in less than 10 years is evident before this committee. It justifies the concern of this committee as to the effects of bomb testing, particularly when we look at the increase of yield. For instance, from 1945, from a 60 kiloton, to 19,000 kilotons for the United States and the United Kingdom. Of course, from 1945 to 1951, the 60 kiloton of the Soviets to the 21,000 in the period 1957 to 1958.

Going then to the last table, No. 3, you have shown where the increase from the 1945–51 period in total kilotons runs in the nature of 85,000 in the last period and beginning with about 760 kilotons in the first period of 1945 to 1951, it is about from 750 kilotons to 85,000 kilotons in the 1957–58 period.

Of course, we want to point out that such effects as are occurring are occurring as a result of all nations engaged in nuclear tests—the United States, the United Kingdom, and the Soviet Nation up to date—and we understand that there may be tests by the French Government in the Sahara this year. We face the likelihood of other nations developing these weapons and having the same desire to progress in this field as the present nations, and, therefore, there will be a greater potential hazard in this area.

If there are other points that you would like to bring out that are of significance in the summary, you may do so.

Dr. DUNHAM. I think I have taken more time than I was entitled to, Mr. Holifield. Later during the hearings I hope I may make further comments.

Representative HOLIFIELD. Thank you very much. Are there any questions from members of the committee?

Representative VAN ZANDT. Doctor, you mentioned the reports that are originating in the various laboratories and the fact that they are available. Has the demand for them been very great?

Dr. DUNHAM. I don't know what the turnover of those reports is, Mr. Van Zandt. People that want this sort of thing want it badly. I don't think it is important that 10,000 people have asked for them. The important thing is that those who want it and are thinking about these things have the material available to them.

Representative VAN ZANDT. You indicate that you plan to establish a system of regular quarterly public information releases on fallout. Why have you waited until this date to adopt this system of reports?

Dr. DUNHAM. I don't think it was a question of waiting. I think it was a question of being perhaps preoccupied with other things, and

we feel very definitely this is an important thing that must be done.

Representative VAN ZANDT. Could the declassification of information in this field be one of the reasons why you have delayed inaugurating this system?

Dr. DUNHAM. No. The type of thing that we would be doing in the quarterly report would be summarizing the quarterly reports of the Health and Safety Laboratory data which come out from a layman's standpoint in a relatively undigestible form, I must be perfectly frank to admit.

Representative VAN ZANDT. That is all.

Representative PRICE. Dr. Durham, you have made a very fine and valuable contribution to the committee as you did 2 years ago, and as you have always done when you have appeared before the committee. I think the answer to almost every question thath as been raised can be found somewhere in the paper that you have delivered to us this morning. But I think we should be practical about it and hit what might be said to be the fear of the average layman and average citizen throughout the country. Could you give me a categorical reply to, is there any justification for fear on the part of people living in these hotspot areas, for instance the St. Louis milkshed, or the Minnesota wheatfield area?

Dr. DUNHAM. The most pessimistic assumptions of the effects of fallout are related really to statistical and mathematical probabilities of individuals having difficulties. As long as the variation is not marked from one area to another, the relative hazard of living in one place or another in terms of whether the milk is running tens of strontium units or 18 or something like that, is very, very small. It is very small.

Representative PRICE. So you would say that there is actually no justification for fear on the part of citizens?

Dr. DUNHAM. No one should be alarmed.

Representative PRICE. Where you direct yourself to the point in the summary statement, you were referring to how clean can a nuclear weapon be. Do you know of any scientist who has a hope of producing an absolutely clean weapon, one from which there would be no harmful fallout?

Dr. DUNHAM. I am not aware of one, but that would not necessarily follow that I was stating a fact. I just don't happen to know of anybody who has that thought.

Representative PRICE. Even if there were, it would not be a uniform production. Some other people might not be as careful in the production of weapons.

Dr. DUNHAM. Yes.

Representative PRICE. I think that is all I have.

Representative HOLIFIELD. Mr. Bates.

Representative BATES. Dr. Dunham, I could not help thinking as I listened to you discuss the various risks which we take in ordinary life comparing 41,000 deaths on the highway each year to the matter which is now before us. How many, if any, lives have been lost through radioactive material?

Dr. DUNHAM. How many have been lost?

Representative BATES. Yes.

Dr. DUNHAM. I think one can state—would this include the casualties in Japan?

Representative BATES. No.

Representative HOLIFIELD. Are you directing your question to radioactive fallout from peacetime testing or from the war use in Hiroshima and Nagasaki?

Representative BATES. I am not talking about the bombing, but the testing originally in the Manhattan project and from that time down to now.

Dr. DUNHAM. We know of three individuals who died as a direct and quite immediate result of radiation accidents. There is no question about it.

Representative PRICE. If the gentleman would yield, I wonder if the gentleman would also have in his mind casualties caused from ionizing radiation?

Representative BATES. If you are asking me if I had it in mind, I didn't specifically. I am thinking of all kinds of exposure except bombing.

Representative PRICE. I think we should find out the true facts.

Dr. DUNHAM. I was referring to ionizing radiation. This is the radiation we are talking about from fallout.

Representative PRICE. I think perhaps Mr. Bates had this in mind. Would you give the committee the benefit of your views on the difference between the two, and if you have any information on casualties in this area, could you state them?

Dr. DUNHAM. The three deaths, all of which occurred at Los Alamos, were the direct result of ionizing radiation—mixed gamma-neutron radiation—in criticality accidents. Accidents in some way similar to the one that occurred in Oak Ridge a year ago last June, or pretty nearly 2 years ago. It was just about a year ago.

Representative PRICE. In this area you would go farther back than the Manhattan District and take the radium dials.

Dr. DUNHAM. Going back into what are called the X-ray models, the early pioneer radiologists and physicists, there were a number who died of cancer, I don't know just how many, or of anemia. Madam Curie herself was probably a victim, though she lived to be 70 before it caught up with her, of a fairly sizable body burden of radium. Of course, it is quite well known the number of radium-dial workers who died because they got radium in their bones as a result of pointing the tips of their brushes with their tongues and that sort of thing. Those casualties there is no question about.

Representative BATES. What I had in mind was how many lives have we lost, if any, since we started the Manhattan project as far as radiation is concerned, from testing. I mean accidents or exposure.

Dr. DUNHAM. Three that you can directly relate.

Representative WESTLAND. Will the gentlemen yield? I think it should be brought out here that through the use of radioactive isotopes in medicine and biology, it is estimated that more lives have been saved through these materials than were lost in Hiroshima.

Dr. DUNHAM. This estimate has been made by a number of people, and as far as I know, it is probably still a perfectly valid estimate.

Representative WESTLAND. My authority is Dr. Lawrence at the Lawrence Radiation Laboratory.

Dr. DUNHAM. Yes, sir.

Representative BATES. If I still have the floor, it does appear that it is difficult to find any field of endeavor which has had such a wonderful standard of safety as this particular field.

Dr. DUNHAM. I think the record is very good. We are very proud of it.

Representative VAN ZANDT. Will the gentleman yield?

Representative BATES. Yes.

Representative VAN ZANDT. Doctor, the three accidents you mentioned, so that they will be understood, one was at Los Alamos?

Dr. DUNHAM. The three were at Los Alamos.

Representative VAN ZANDT. Dr. Graves survived one of the accidents, did he not?

Dr. DUNHAM. Very much so. He is very active today. I believe he is in Geneva today.

Representative VAN ZANDT. How much of a dose did he take?

Dr. DUNHAM. Somewhere in the vicinity of 300 to 350 roentgens equivalent.

Representative VAN ZANDT. What in the way of a dose did the physicists take who died?

Dr. DUNHAM. One got a dose up around a thousand.

Representative VAN ZANDT. He died and Dr. Graves survived.

Dr. DUNHAM. That is correct.

Representative VAN ZANDT. Thank you.

Representative HOLIFIELD. Thank you very much. Mr. Westland.

Representative WESTLAND. Mr. Chairman, I might ask just one question. At the bottom of page 18, Doctor, the statement you make there with all the milk sampling averaging under 30, I believe, micromicrocuries of strontium 90?

Dr. DUNHAM. Yes, sir.

Representative WESTLAND. It is unlikely that the average level of radiation of strontium 90 from weapons tests detonated to date will equal the sea level natural background exposure. Could you explain that in words of one syllable?

Dr. DUNHAM. Yes. What I am trying to point out is that the number of micromicrocuries of strontium 90 in the body which would give a dose equivalent to the natural sea level radiation is roughly 30 micromicrocuries. As testimony will develop later in the week, there is every reason to believe that the body burden will be something less than whatever the figure is in milk. So I am just setting a ceiling, as it were, on what could happen.

Representative WESTLAND. You mean to say if I live at sea level, I get an amount of radiation equal to what has happened from all these bomb tests?

Dr. DUNHAM. No, sir. I am saying that what you would get as a result of the bomb testing would not equal what you get as you live at sea level. It would not be that high.

Representative WESTLAND. What if I lived in Denver. Is there any difference?

Dr. DUNHAM. It would be a little higher in natural background. It would still be a smaller relative amount from fallout.

Representative WESTLAND. Thank you.

Representative HOLIFIELD. Thank you very much for your testimony.

We are running a little behind. We will have Dr. Francis Weber as our first witness when the committee convenes at 2 o'clock. I understand Dr. Libby will be on the witness stand this afternoon.

(The material referred to in Dr. Dunham's oral testimony follows:)

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BONE DOSES FROM STRONTIUM-90

BY W. F. LIBBY*

GEOPHYSICAL LABORATORY, CARNEGIE INSTITUTION OF WASHINGTON, D.C.,
AND U.S. ATOMIC ENERGY COMMISSION

Communicated December 1, 1958

For condensed systems beta radiation is exponentially absorbed[1] with an absorption coefficient, μ, given by:

$$\mu = \frac{(1 + M/100)}{1.27 \times 55E^{3/2}}, \tag{1}$$

where μ is given in units of cm^2/mg, E is the maximum energy of the beta spectrum in millions of electron volts, and M is the average atomic weight of the absorbing medium. It seems reasonable to apply this relation to radiation-dose calculations, assuming the energy spectrum to vary relatively little with absorber thickness. The purpose of this note is to apply this method to bone-dose calculations for Sr^{90} in equilibrium with its daughter, radioactive Y^{90}.

Thus for bone which has a composition such that $M = 13$ approximately, Sr^{90} ($E = 0.61$ Mev) and its daughter Y^{90} ($E = 2.18$ Mev) have absorption coefficients of 0.0313 cm^2/mg and 0.00492 cm^2/mg, respectively. For an effective bone density of 2.0 gm/cm^3, the linear coefficients would be 62.6 cm^{-1} and 9.8 cm^{-1}, respectively. Since the average energies are some 40 per cent of the maximum energy for ordinary beta spectra, the rates of energy deposition per gram of bone for a uniform Sr^{90} burden of 1 μc per 1,000 gm. of bone Ca or 7 kg. of bone, as in the Standard Man[2] would be

$$\frac{2.2 \times 10^6 \times 0.53 \times 10^6 \times 0.40(0.61 + 2.18) \times 1.6 \times 10^{-6}}{7 \times 10^3 \times 10^{-1}},$$

or 2,900 mrad/year.

More importantly, the absorption coefficients of 62.6 cm^{-1} and 9.8 cm^{-1} give the energy distribution around the bone crystals of finite size. Since 78 per cent of the energy is from Y^{90}, the range of its radiation is almost dominant. For it, the mean range is 1.0 mm. or 1000 μ. Similarly for Sr^{90} the mean range is 160 μ.

Thus concentrations of Sr^{90} on a microscopic scale will average out so that no correspondingly abnormally high local doses will result. In other words, an acute dose of strontium-90, which coats the surfaces of the bone crystals by exchange, will produce nearly the same dose throughout the bone as the same amount of Sr^{90} grown in at a steady and uniform rate if the bone trabeculae sizes are smaller than about 100 μ, which is generally thought to be the case.[3]

This point can be seen perhaps more clearly in Figure 1, where the dose rates for an infinite sandwich—infinite in lateral area and infinite in numbers of layers—of bone and marrow (for which $M = 6$) are given. The bone layers were taken to be 100 μ thick and the marrow λ μ thick, and the other constants are given above. The equations for the dose rates in millirad per year at the centers of the layers

derived on the exponential absorption methodology are as follows:

$$\text{Marrow rate} = 7.5\sigma\left(\frac{0.263e^{-0.00145\lambda}}{1-0.535e^{-0.00290\lambda}}+\frac{0.1863e^{-0.000225\lambda}}{1-0.9063e^{-0.00045\lambda}}\right),$$

$$\text{Bone rate} = 7.5\sigma\left(0.2684+\frac{0.2073e^{-0.0029\lambda}}{1-0.535e^{-0.0029\lambda}}+\frac{0.1945e^{-0.00045\lambda}}{1-0.9063e^{-0.00045\lambda}}\right),$$

where σ is the specific activity of the bone in micromicrocuries of Sr^{90} per gram of bone (cf. appendix for derivations).

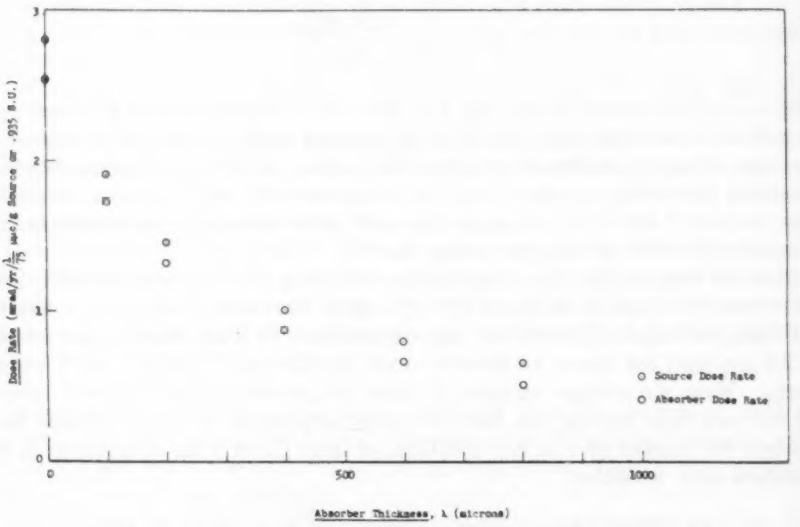

Fig. 1—Central dose rates for infinite sandwich of Sr^{90} sources 100 microns thick interleaved with absorbers λ microns thick.

Oliver and Vaughan[4] calculate for a cylindrical shell of source material 100 μ thick and radius ~1 mm. They estimate a dose of 1.58 rad/hr at the center of the shell and 0.40 rad/hr at the center of the marrow resulting from a concentration of about 5.4 μc/g. For a concentration of 1 $\mu\mu$c/g this becomes 2.56 mrad/yr and 0.649 mrad/yr, respectively, with a ratio of

$$\frac{\text{Max. dose in bone}}{\text{Min. dose in marrow}} \sim 4.$$

Our method gives a dose rate at the center of the shell

$$7.5\ \sigma\ [0.61\ (1-e^{-50\times 0.0313\times 2\times 10^{-1}})+2.18\ (1-e^{-50\times 0.00492\times 2\times 10^{-1}})]$$
$$= 2.04\sigma$$
= 2.04 mrad/year for σ of 1 $\mu\mu$c/g.

The central marrow rate would be

$$7.5\,\sigma\left[(0.61\,\frac{(1-e^{-100\times 0.0313\times 2\times 10^{-1}})}{0.0313}\,0.029e^{-950\times 0.029\times 10^{-1}}\right.$$

$$\left.+\,2.18\,\frac{(1-e^{-100\times 0.00492\times 2\times 10^{-1}})}{0.00492}\,0.0045e^{-950\times 0.0045\times 10^{-1}}\right]$$

$= 1.21\sigma$

$=$ 1.21 mrad/year for σ of 1 $\mu\mu$c/g, giving a ratio of 1.7.

Engstrom *et al.*[3] for a sandwich model with a source layer 70 μ thick and absorber layer of 900 μ calculate 4.93 mrad/yr as bone maximum and 2.19 mrad/yr as absorber minimum, with a ratio of about 2.2.

Our method gives 3.40 mrad/yr at the center of the 70 μ bone layer and 2.57 mrad/year at the center of the 900 μ marrow layer for a ratio of 1.3.

APPENDIX

Problem of Sr^{90} Radiation Doses in an Infinitely Thick Sandwich Infinite in Lateral Extent with Sr^{90} in One Set of Layers Only

Assume mean energy is 40 per cent of maximum energy.	
Thickness of source layers	l (microns)
Density of source layers	ρ_s (g/cc)
Absorption coefficient of $Sr^{90}\beta$ in source layers	μ_s^{Sr} (cm²/mg)
Absorption coefficient of Y^{90} in source layers	μ_s^{Y} (cm²/mg)
Thickness of absorber layers	λ (microns)
Density of absorber layers	ρ_a
Absorption coefficient of $Sr^{90}\beta$ in absorber layers	μ_a^{Sr}
Absorption coefficient of Y^{90} in absorber layers	μ_a^{Y}
Specific activity of source layer	σ ($\mu\mu$c/g)

$$\left|\frac{l}{2}\right| \quad \lambda \quad \left|\frac{l}{1}\right| \quad \lambda \quad \left|\frac{l}{1}\right| \quad \lambda \quad \left|\frac{l}{2}\right| \quad \lambda \quad \left|\frac{l}{3}\right|$$

DOSE RATE FOR MIDPOINT IN ABSORBER LAYER

Contributions from Layers No. 1 (mrad/yr):

$$\sigma\,2.2\times 0.53\times 10^{6}\times 1.6\times 10^{-6}\times 10\times 0.40\left[0.61\times 1000\,\mu_a^{Sr}\times\right.$$

$$\frac{(1-e^{-l\mu_s^{Sr}\times 10^{-1}\rho_s})}{1000\,\mu_s^{Sr}}\,e^{-\frac{\lambda}{2}\mu_a^{Sr}\times 10^{-1}\rho_a}+2.18\times 1000\,\mu_a^{Y}\times$$

$$\left.\frac{(1-e^{-l\mu_s^{Y}\times 10^{-1}\rho_a})}{1000\,\mu_s^{Y}}\,e^{-\frac{\lambda}{2}\mu_a^{Y}\times 10^{-1}\rho_a}\right]$$

Contributions from Layers No. 2:

$$\sigma\,7.5\left[0.61\times 1000\,\mu_a^{Sr}\,\frac{(1-e^{-l\mu_s^{Sr}\times 10^{-1}\rho_s})}{1000\,\mu_s^{Sr}}\,e^{-\frac{\lambda}{2}\mu_a^{Sr}\times 10^{-1}\rho_a}\times\right.$$

$$(e^{-\lambda\mu_a^{Sr}\times 10^{-1}\rho a}-l\mu_s^{Sr}\times 10^{-1}\rho_s)+2.18\times 1000\,\mu_a^{Y}\,\frac{(1-e^{-l\mu_s\times 10^{-1}\rho_s})}{1000\,\mu_s^{Y}}\times$$

$$\left.e^{-?\mu_a^{Y}\times 10^{-1}\rho_a}\,(e^{-\lambda\mu_a\times 10^{-1}\rho_a}-l\mu_s^{Y}\times 10^{-1}\rho_s)\right].$$

Total for infinite number of layers:

$$\sigma\, 7.5\Bigg[0.61 \times 1000\, \mu_a^{Sr} \frac{(1 - e^{-l\mu_s^{Sr} \times 10^{-1}\rho_s})}{1000\, \mu_s^{Sr}}\, e^{-\frac{\lambda}{2}\mu_a^{Sr} \times 10^{-1}\rho_a} \times$$

$$\left(\frac{1}{1 - e^{-\lambda\mu_a^{Sr} \times 10^{-1}\rho_a - l\mu_s^{Sr} + 10^{-1}\rho_s}}\right) + 2.18 \times 1000\, \mu_a^{Y} \frac{(1 - e^{-l\mu_s^{Y} \times 10^{-1}\rho_s})}{1000\, \mu_s^{Y}} \times$$

$$e^{-\frac{\lambda}{2}\mu_a^{Y} \times 10^{-1}\rho_a}\left(\frac{1}{1 - e^{-\lambda\mu_a^{Y} \times 10^{-1}\rho_a - l\mu_s^{Y} \times 10^{-1}\rho_s}}\right)\Bigg]$$

or

$$7.5\, \sigma\Bigg[\frac{0.61\, \frac{\mu_a^{Sr}}{\mu_s^{Sr}}\, (1 - e^{-l\mu_s^{Sr} \times 10^{-1}\rho_s})\, e^{-\frac{\lambda}{2}\mu_a^{Sr} \times 10^{-1}\rho_a}}{1 - e^{-\lambda\mu_a^{Sr} \times 10^{-1}\rho_a - l\mu_s^{Sr} \times 10^{-1}\rho_s}}$$

$$+ 2.18\, \frac{\mu_a^{Y}}{\mu_s^{Y}}\, \frac{(1 - e^{-l\mu_s^{Y} \times 10^{-1}\rho_s})\, e^{e^{-\frac{\lambda}{2}\mu_a^{Y} \times 10^{-1}\rho_a}}}{1 - e^{-\lambda\mu_a^{Y} \times 10^{-1}\rho_a - l\mu_s^{Y} \times 10^{-1}\rho_s}}\Bigg]$$

For

$\mu_s^{Sr} = 0.0313$ cm²/mg, $\mu_s^{Y} = 0.00492$ cm²/mg,
$\mu_a^{Sr} = 0.029$ cm²/mg, $\mu_a^{Y} = 0.0045$ cm²/mg,
$\rho_s = 2$, $\rho_a = 1$,
$l = 100$,

or

$$\textit{Central absorber dose} = 7.5\, \sigma\Bigg[\frac{0.565\, (1 - e^{-0.626})\, e^{-0.00145\lambda}}{1 - e^{-\lambda 0.00290\lambda - 0.626}}$$

$$+ \frac{2.02\, (1 - e^{-0.0984})\, e^{-0.000225\lambda}}{1 - e^{-0.00045\lambda - 0.0984}}\Bigg]$$

$$= 7.5\, \sigma\left[\frac{0.263e^{-0.00145\lambda}}{1 - 0.535e^{-0.00290\lambda}} + \frac{0.1863e^{0.000225\lambda}}{1 - 0.9063e^{0.00045\lambda}}\right]$$

Value for $\lambda = 0$ and $\sigma = 1/7.5$ $\mu\mu$c/g = 0.935 S.U. is 2.585 mrad/yr.
Dose rate/S.U. = 2.76 mrad/yr.

Similarly,

Central source dose:

$$7.5\, \sigma\Bigg(0.61\Bigg[(1 - e^{-\frac{l}{2}\mu_s^{Sr} \times 10^{-1}\rho_s}) +$$

$$\frac{(1 - e^{-l\mu_s^{Sr} \times 10^{-1}\rho_s})\, e^{-(\lambda\mu_a^{Sr} \times 10^{-1}\rho_a + \frac{l}{2}\mu_s^{Sr} \times 10^{-1}\rho_s)}}{1 - e^{-(\lambda\mu_a^{Sr} \times 10^{-1}\rho_a + l\mu_s^{Sr} \times 10^{-1}\rho_s)}}\Bigg] + 2.18 \times$$

$$\Bigg[(1 - e^{-\frac{l}{2}\mu_s^{Y} \times 10^{-1}\rho_s}) + \frac{(1 - e^{-l\mu_s^{Y} \times 10^{-1}\rho_s})\, e^{-(\lambda\mu_a^{Y} \times 10^{-1}\rho_a + \frac{1}{2}\mu_s^{Y} \times 10^{-1}\rho_s)}}{1 - e^{-(\lambda\mu_a^{Y} \times 10^{-1}\rho_a + l\mu_s^{Y} \times 10^{-1}\rho_s)}}\Bigg]\Bigg) =$$

$$7.5\, \sigma\left[0.2684 + \frac{0.2073e^{-0.0029\lambda}}{1 - 0.535e^{-0.0029\lambda}} + \frac{0.1945e^{-0.00045\lambda}}{1 - 0.9063e^{-0.00045\lambda}}\right]$$

Value for $\lambda = 0$ and $\sigma = 1/7.5 = 2.790$ mrad/yr.
Value for 1 S.U. and $\lambda = 0 = 2.998$ mrad/yr.

* On leave from the University of Chicago.

[1] A. D. Suttle, Jr., and W. F. Libby, *Anal. Chem.*, **27**, 921, 1955; W. F. Libby, *Anal. Chem.*, **29**, 1566, 1957.

[2] *N.B.S. Handbook*, No. 52 (1953).

[3] A. Engstrom, R. Bjornerstedt, C-J. Clemedson, and A. Nelson, *Bone and Radiostrontium* (New York: John Wiley & Sons, Inc., 1957), p. 97.

[4] R. Oliver and Janet Vaughan, "An Attempt To Assess the Dosage of Strontium-90 Received by Young Rabbit Bone," *Brit. J. Radiol.*, **29**, 668, 1956.

Appendix A

STATEMENT ON BIOLOGICAL HAZARDS OF CARBON-14

(See also vol. 3, app. G.)

Prepared by M. R. Zelle, Chief, Biology Branch
Division of Biology and Medicine
U. S. Atomic Energy Commission

In the preparation of the agenda for the Joint Committee on Atomic Energy 1959 fallout hearings, it was suggested that a statement be prepared on the biological hazards of carbon-14. A consideration of this important problem was published first in September, 1958 as Washington Technical Report 1008 entitled "The Biological Hazard to Man of Carbon-14 From Nuclear Weapons," by John R. Totter, M. R. Zelle, and H. Hollister, and later republished in SCIENCE, December 12, 1958, Vol. 128, No. 3337, pages 1490-1495 under the title "Hazard to Man of Carbon-14." Then in January, 1959, additional comments on this subject were provided in a letter to Mr. Ramey, Executive Director of the Joint Committee from the General Manager, AEC, a copy of which is attached. Only a few additional comments are required to bring the Committee completely up to date on this problem.

First, it should be recalled that whereas most internal radioisotopes produced potential biological damage only by the radiation emitted during radioactive decay, carbon-14 theoretically could also produce damage by its transmutation to nitrogen since the carbon-14 atoms may be an integral part of the structure of biologically important molecules such as genes and enzymes. This latter possibility is particularly important and interesting in connection with mutations which could result from transmutation of carbon-14 atoms which are incorporated into the genetic material, deoxyribonucleic acid. Whereas Totter, Zelle and Hollister (SCIENCE, Vol. 128, No. 3337, pages 1490-1495) concluded that mutations from carbon-14

transmutation could possibly be an important source of biological damage, Pauling (SCIENCE, November 14, 1958, Vol. 128, No. 3333, pages 1183-1186) did not consider it to be a serious problem.

It should be emphasized that biological damage from carbon-14 transmutation is still only a theoretical possibility; there is as yet no convincing experimental evidence for it. Furthermore, the clear cut demonstration of mutations due to carbon-14 transmutations will be difficult since one must show that the total mutation rate is too high to be attributed solely to the beta radiation produced during radioactive decay. Critical and specialized genetic techniques will be required. At the present time, studies of specific mutations in special strains of bacteria having genetic requirements for particular purine and pyrimidine constituents of nucleic acids appear to be the most inviting experimental approaches. The writer knows of only one small study in which such experimental methods are being utilized. This work is being carried out at the Hanford Biological Operation of the Atomic Energy Commission. However we are supporting several projects where other experimental approaches bearing on this problem are being examined. Obviously, a much greater research effort is required but it is difficult to attract competent investigators to such a difficult problem with its lack of assurance of definitive results. In this connection, data on the comparative efficiencies per roentgen of lethality and of mutations at specific loci in bacteria would be valuable in permitting more accurate quantitative estimation of the experimental possibility of detecting mutations caused by carbon-14 transmutations and of their potential seriousness as a biological hazard.

The question of genetic effects from carbon-14 transmutations was discussed by the United Nations Scientific Subcommittee on Radiation during its 1959 session. The types of possible genetic damage, the possible magnitude

of the transmutation damage, and the various experimental approaches to the detection and quantification of the damage were all discussed. The United Nations Scientific Subcommittee unanimously agreed that the potential biological hazard of carbon-14 was an important and somewhat neglected problem, and urged that more research effort should be directed towards the carbon-14 problem.

January 8, 1959

Mr. James T. Ramey
Executive Director
Joint Committee on Atomic Energy
Congress of the United States

Dear Mr. Ramey:

In reply to your letter of December 5, 1958 I would like to give you the following comments prepared by my staff on Dr. Pauling's paper (Science, 128, November 14, 1958):

1. By and large the details of the calculations appear reasonable considering the general dearth of information by which to verify the assumptions. The effect of an assumption that the world population will stabilize in hundreds of years at five times the present population naturally tends to increase one's estimate of the genetic danger of C-14, because C-14 has a long radioactive lifetime. On the other hand, no one doubts that the world's population is growing.
2. Dr. Pauling's estimate for the infinity dose from C-14 for the testing through 1958 would be, p. 1185 of paper, (5) (12.7) = 64 milliroentgens. This value might be compared with the infinity dose from ordinary fallout from testing to date. The United Nations Scientific Committee's report, p. 14, gives the maximum 30-year dose to the gonads from stratospheric fallout (i.e., from Cs-137) for testing through 1958 as 10 milliroentgens. The corresponding infinity dose would be about 16 milliroentgens and if we add about 3 milliroentgens for external and internal gamma dose from tropospheric fallout we get about 19 milliroentgens.
3. Thus Dr. Pauling's suggestion that C-14 may well represent a larger genetic danger than ordinary fallout may be correct if one

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accepts that it is proper to compare an infinity dose delivered over an effective period of 8000 years to one delivered over an effective period of about 40 years.

4. If one does not use Dr. Pauling's factor of five for an expanding population but does use the factor of two for transmutation effects, as derived in report WASH-1008 (The Biological Hazard to Man of Carbon-14 from Nuclear Weapons, copies of which went to the Joint Committee) under assumptions that make this effect considerably more important than Dr. Pauling's assumptions make it, then Dr. Pauling's genetic damage estimates for all generations following the end of testing through 1958 agree with those in WASH-1008:

	Dr. Pauling, modified as noted	WASH-1008, Table I
gross defects	1.2×10^5	1.0×10^5
stillbirths and childhood deaths	3.8×10^5	3.8×10^5
embryonic and neonatal deaths	9.0×10^5	9.0×10^5

5. Table I of WASH-1008 presents further tabular information comparing estimated genetic defects from bomb C-14 from testing to date with genetic defects from natural C-14 and from all natural background radiation. All of these estimates are for the same period of time, i.e., the 8000-year average lifetime of C-14. As Table I shows, the numerical estimates of damage from C-14 from testing are much smaller than those from natural C-14 or from all natural background radiation. Therefore, it would appear from the close

agreement between Dr. Pauling's estimates of C-14 damage and those in WASH-1008 that Dr. Pauling also would agree that C-14 damge from testing to date, on an absolute or on a percentage basis, is much smaller than from the other two sources of damage. Dr. Pauling says words to this effect in his paper, p. 1184. Furthermore, by the arguments Dr. Pauling gives, it would appear that Dr. Pauling would also agree that genetic damage from ordinary fallout is even smaller still. This does not imply that either C-14 or ordinary fallout genetic damage can be ignored.

If we can be of further help on this subject we would appreciate the opportunity to help.

Sincerely yours,

/s/ A R Luedecke

General Manager

APPENDIX "B"

CURRENT AEC RESEARCH
CONTRACTS AND PROGRAMS IN SOIL CHEMISTRY AND MINERAL METABOLISM OF PLANTS

Prepared by the Division of Biology and Medicine
U.S. Atomic Energy Commission

1. Title: Collection and Preparation of Soils, Plants, and Animals for Calcium and Strontium Analyses
U. S. Department of Agriculture $48,892 L. T. Alexander

The objectives of this project are to determine the worldwide distribution of strontium-90 in soils, plants, and animals, and to contribute to an understanding of the meteorological factors determining the distribution of radioactive fallout. Emphasis is given to soil characteristics and landscape features that determine the retention of strontium-90 in place or subsequent movement after deposition. At a number of locations the relation between soils, plants, and animals is followed on a continuing basis. Interpretation of the data is made in terms of significance of strontium-90 in the food chain of man.

2. Title: Equipment and Methods for Decontamination of Agricultural Lands Contaminated by Radioactive Fallout
U. S. Department of Agriculture $25,000 Walter C. Hulburt

Feasible procedures for the large-scale economical decontamination of agricultural lands with power implements are investigated. These entail the removal of standing crops, crop residues, or of a surface layer of the soil itself. In the last case, a successful method must not reduce drastically the depth of the productive surface soil. The criterion of effectiveness of a procedure is the percentage of the applied quantity of radioactive contaminant, such as Ba-140 or P-32, remaining on the land. During the first year of experimentation the following materials were utilized: sand and silt loam soils, plowed, disked, and harrowed, grass sod, Sudan grass, soybeans, and straw mulches; sod-cutter, mower, flail forage chopper, rake, sidewalk and farm rollers, and road maintainer. Cementing agents for consolidating fallout with the surface soil prior to removal, such as asphalt emulsion, are tested.

3. Title: Accumulation and Movement of Fission Products in Soils and Plant
U. S. Department of Agriculture $90,000 R. F. Reitemeier

The behavior of nuclear fission products in soils, their availability to plants, their root and foliar absorption, and consequent distribution within plant parts, are investigated by laboratory, greenhouse, growth chamber, and field experimentation. Attention is centered on the long-lived fission products, especially strontium-90 and cesium 137.

The redistribution of deposited fallout by rain, erosion, and run-off, and methods for the decontamination of agricultural land are investigated in the field. Current and recent laboratory and greenhouse studies include the extent of movement of radiocesium and radiostrontium under leaching, the possibility of fixation of strontium in non-exchangeable states, adsorption sites of strontium on clay surfaces, effects of natural exchangeable calcium and of lime on uptake of strontium, and factors affecting the foliar absorption of strontium.

4. Title: Utilization of Phosphorus from Biological Material and Uptake of Strontium by Various Type Crops
University of Arizona $6500 W. H. Fuller

Various aspects of the availability to plants of radiostrontium and phosphorus in calcareous soils are investigated. Successive crops are grown on contaminated soils to determine the length of time needed to reduce the crop contamination to a low level. The influence of crop residues and organic materials on increasing the native available soil calcium and thereby reducing the strontium contamination of plants is studied. Results indicate that such organic residues increase the availability of native soil phosphorus. The effects of different forms of nitrogen on the uptake of phosphorus from crop residues also are being examined.

5. Title: Study of the Internal or Metabolic Factors and the External or Environmental Factors Affecting Ion Absorption by Plants
University of California $13,831 Louis Jacobson & Roy Overstreet

The mechanisms and kinetics of element absorption by plant roots and root cells are investigated by radioisotope techniques. Underway currently is clarification of the status of absorbed ions in excised roots, which information will help to delineate the roles of vacuole and cytoplasm in the absorption process. Factors controlling the loss of previously absorbed ions are studied in order to test the hypothesis that absorption involves structural binding by the cell. In the continuation of studies on carbon dioxide fixation by roots and cell particulates, emphasis is to be given to elucidation of the relationship between absorption, carbon dioxide fixation, and malic acid synthesis.

6. Title: An Investigation into the Utility of Radiation Sterilized Soil as a Medium for Growth of Plants and Microorganisms.
University of California $12,898 A. D. McLaren

The benefits of the sterilization of soil by ionizing radiation, relative to other sterilization methods, for studies of soil microbiology, soil biochemistry, and plant nutrition are explored under this project. The radiation sources will include linear accelerators and possibly gamma, x-ray, and neutron sources. The contribution of rhizosphere organisms to plant growth will be examined. Attempts will be made to determine the fraction of the total organic phosphorus of the soil that is available to plants. Studies of single microbial activities in soil, for example nitrification, or even the kinetics of a complete nitrogen cycle should be possible in electron sterilized soil.

7. Title: Study of the Decontamination of Soils Containing Radioactive Elements and Salts
University of California $22,781 Roy Overstreet

Recent research under this project included the leaching of contaminated soils with large amounts of acid and salts, and the application of asphalt to the soil surface to consolidate the contaminants with the soil for efficient removal. Some of the leaching treatments were effective, but the relatively high cost and probable damage to the soil precluded continuation of the studies. The asphalt emulsion treatment was effective up to 97% on small plots, but special removal machinery would be needed for large field areas. The current program is concerned with the soil chemistry and plant uptake of fission products from California soils. Aspects under investigation include the fixation, availability, and soil-plant discrimination factors for radiostrontium and radiocesium, and reactions of radioiodine with soil organic matter.

8. Title: Study of the Behavior of Certain Chelating Agents in Biological and Soil Systems
University of California $10,705 Arthur Wallace

The effects of various synthetic chelates on decreasing or increasing the absorption of radioactive contaminant and nutrient ions by plants and on their internal metabolism are investigated. The mechanism of absorption is studied by techniques of chemical kinetics. Observations that certain metal chelates are irreversibly fixed on clay in soils will be extended to other chelates and various metals, including fission products. The nature of separation of metals from chelates within plants and effects of chelates on activity of enzyme systems also are examined.

9. Title: Distribution of Nuclear Fallout
Columbia University $113,554 J. L. Kulp

This experimental and monitoring program on the distribution of fallout nuclides in the biosphere includes work on distribution of strontium-90 and other nuclides in soils and plant-derived foods. In the soil program, the uniformity of strontium-90 content of soils in the vicinity of New York City will be investigated. In the food program, current emphasis is directed toward strontium-90 in vegetables and cereals. Domestic samples are obtained in cooperation with the Food and Drug Administration, and foreign samples with the International Committee on Nutrition. As a part of the research on increases in carbon-14, samples of currently growing vegetables will be analyzed, and the results correlated with human samples collected at the same time and place.

10. Title: Ion Interactions in Plant Tissues
University of Connecticut $5,000 Fred H. Emmert

This contract includes basic studies on the uptake of sulfur, phosphorus, and calcium by plant roots and mechanisms of their interactions in plants. The research information gained will ultimately be useful in our understanding of the uptake and metabolism of fission products by plants.

11. Title: Material Transfer between Plants through Adjacent Root Systems
Dartmouth College $7,756 F. H. Bormann

Observations indicated that intraspecies root grafts might provide important pathways for exchange of ions and molecules between trees. Research is devoted to (1) detecting the frequency of root grafts and their relationship to stand and habitat conditions, (2) determining their importance as pathways for transfer of materials, by use of radioisotope tracers as Rh 86 and I-131, (3) estimating their contribution to the competitive ability of the species, and (4) evaluating their significance in silvicultural practice. The initial studies, on white pine, showed a high incidence of root grafts functional in the translocation of foods, minerals, and water, thereby suggesting that some plants operate as a unit having a common physiology.

12. Title: The Path of Radial Movement of Minerals from Soil to Xylem
Duke University $3,853 Paul J. Kramer

Radioisotopes of strontium and phosphorus are used in experiments designed to provide information on the absorption of elements by roots. The points of interest are (1) the pathway of ions moving into roots, (2) the relative importance of passive and active transport, (3) the role of the endodermis, and (4) the extent of absorption through older roots lacking cortex and endodermis. Experimental approaches include the effects of varying the rate of entry of water under a pressure gradient on the rate of entry of ions, and radioautography of radial thin sections of roots following contact with radioisotopes solutions.

13. Title: Plant Biochemistry of Boron
Iowa State College $8,470 Samuel Aronoff

This basic research contract is devoted to a study of the nutritional level of boron in a plant on its metabolism. One aspect of the work may have a bearing on the fallout problem in that it appears that the permeability of plant cell membranes is related to boron levels in the tissues. Information of this type may be useful in understanding fission-product uptake in plants.

14. Title: The Absorption and Utilization of Radioactive Nuclides Applied to Above-Ground Plant Parts
Michigan State University $26,000 H. B. Tukey

This research project has been primarily concerned with the absorption of radioactive materials deposited on the leaves of plants. Of particular interest in connection with fallout studies, it has been found that Ca-45, Sr-89, and Ba-La 140 are absorbed into leaves and other above-ground parts to some extent.

15. Title: The Mechanism of Active Absorption of Radioisotopes by Plant Cells
University of Missouri $3,460 Jacob Levitt

This project involves basic research in the mechanisms by which ions of elements such as phosphorus and calcium are taken up from the surroundings by plant cells. Although this study is not concerned with the uptake of fission products as such, the results obtained will be of interest in this problem.

16. Title: The Relation of Fallout and Other Factors to Soil and Plant Contamination and the Assimilation of Fission Products and Other Factors by Range Livestock
University of Nevada $45,000 V.R. Bohman & C. Blincoe

This project is primarily a documentation study of the pickup of fission products by ordinary range cattle. Three herds of cattle are being studied; one located on the Nevada Test Site, one located approximately 50 miles east of the NTS, and one located in the extreme northeast corner of Nevada, where the fallout is relatively low. Among other lines of investigations, this project involves studies on the fission product levels in soil and in species of plants used as forage by range cattle. These studies are primarily concerned with Sr-90, Cs-137, and I-131, although a few measurements are being made on other fission products.

17. Title: The Mineral Composition of Plants Grown on Southeastern Soils as Related to Soil Characteristics, Lime and Fertilizer Additions, and Rot Distributions, with Particular Emphasis on Strontium-90
North Carolina State College $12,528 N.T. Coleman

The soils of the southeastern United States generally have low cation exchange capacities and low exchangeable calcium content. This results in a higher strontium-90 content in the crops grown in this area and consequently an increased hazard to humans consuming those crops or animal products derived from them. Investigations are conducted on the effects on the uptake of strontium and other cations of the magnitude and source of the cation exchange capacity, the soil acidity and degree of ion saturation, and complementary ion effects occurring through fertilization. The vertical distribution of strontium and other ions in southeastern soils from the viewpoint of ion exchange chromatography, and the root distribution in soils and contributions of different layers to mineral nutrition also are studied.

18. Title: Detailed Characterization of Soil and Vegetation on Selected Sites to Serve as Basis for Future Evaluations of Effects of Radioactive Contamination
Ohio State University $28,794 Nicholas Holowaychuk

Eight sites in Ohio covered by forest and cultivated crops have been characterized as to soil and vegetation. Chemical and physical analyses of the soils have been made including strontium content and radioactivity of the soil horizons. Plant species samples are analyzed for chemical composition, including strontium content. Other investigations include greenhouse experiments on uptake of applied radioisotopes, measurement of the movement and concentration of isotopes applied to field plots by soil, vegetation, erosion, and run-off, and the behavior of strontium in soil and clays in relation to other cations.

19. The Effects of Soil Temperature and Morphological Age of Plants on the Uptake and Assimilation of Radioactive Phosphorus
Oregon State College $7,945 S. B. Apple, Jr.

Interactive effects of substrate temperatures and time of application of phosphorus on the uptake and assimilation of P-32 labeled phosphorus by horticultural plants are investigated. The assimilation of phosphorus by bean plants grown at high soil temperature was found to be significantly higher than by those grown at low soil temperature. This result may be due to one or more factors: (a) increased metabolic activity of roots; (b) larger root system; and (c) high availability of soil phosphorus. The work is being extended to pea plants and to other soil types.

20. Title: Relationship of Soil Properties to Chemical Reactions and Other Phenomena Involving Sulfur
Oregon State College $7,000 Moyle E. Harward

The soil reactions and soil-plant relationships of sulfur in a number of Oregon soils are studied by the use of S-35 as a tracer. Information is sought on the factors associated with the strong tendency of some soils, Brown and Reddish Brown Latosols, to retain sulfate against leaching, including sulfate adsorption capacities of soils and clays, ion exchange phenomena, and type of clay mineral. Estimates of the amount of available residual sulfur in soils are made by radiosulfur tracer experiments with alfalfa.

21. Title: Radioactive Iron Studies with Soils and Crops of Puerto Rico
University of Puerto Rico $3,700 J. A. Bonnet

The iron nutrition of pineapple plants grown on acid, limed, and calcareous soils is investigated with the aid of the tracer Fe-59. The problem currently under study is the relative availability of soil applications and crown applications of iron in the form of radioactive iron chelates. Results have indicated that the pineapple leaves derive more iron from the chelate when it is applied to the crown.

22. Title: Research Concerning the Accumulation of Radioactivity by Plants. 27.
University of South Carolina $4,602 Wade T. Batson

The differential uptake of radioactive isotopes by various species of plants native to the Savannah River Plant is measured. Plants are grown in potted soil to which production mixture has been applied, and plant samples are assayed by counting apparatus and X-ray film technique.

23. Title: An Ecological Study of the Vascular Shore Plants of the PAR Reservoir, Savannah River Plant
University of South Carolina $8,756 William R. Kelley

Ecological data on the vegetational associations and plant species which invade or persist in the shore and margin of the PAR reservoir are collected. The uptake by these plants of radioactive contaminants 28.
which are expected to be released into the reservoir is to be determined by radiological assay. The physical ecological factors to be measured include meteorological data and soil characteristics and conditions.

24. Title: Metabolism of Selenium and Sulfur in Plants
South Dakota State College $4,320 E. I. Whitehead

This project investigates the uptake and translocation of selenium in plants, especially as influenced by substances such as arsenite and arsenate. While this project is not concerned directly with fission product metabolism in plants, the basic information being gained may prove to be valuable in fallout studies.

25. Title: Vegetation Studies Related to Movement of Radioactive Wastes
University of Tennessee $21,986 Royal E. Shanks

Studies of the vegetational and successional changes in the plant populations growing in the contaminated areas of the White Oak Lake bed, Oak Ridge, are conducted. The procedure involves sampling, analysis, studies of organic and mineral matter, and uptake and deposition of radioactivity. Pot culture experiments with native and cultivated plant species on homogenized silt from the lake bed at moderate levels of radioactivity are also conducted.

26. Title: Use of Radioisotopes in Studying Lime-induced Chlorosis
Utah State University $8,500 R.L. Smith & H. H.Wiebe

The current program of this project includes studies of the effects of pH and bicarbonate concentration on chlorosis, studies of factors affecting 29.
iron translocation in plants, determination of the root cation exchange capacities of a number of plants, and effects of chelates on translocation and nutrient composition of plants. Lime-induced chlorosis has been definitely associated with decreased iron absorption and translocation. The concentration of bicarbonate has been shown to have more effect on chlorosis than has pH. Studies with C-14 demonstrated that bicarbonate C is absorbed readily and becomes widely disseminated in plant tissues. High levels of P, Mn, Zn, Fe, and calcium nitrate in nutrient solutions have significantly inhibited translocation of foliar applied iron.

27. Title: The Chemical Characteristics and Physiological Effects of Selenium
University of Wyoming $9,500 Irene Rosenfeld, O. A. Beath, and H.F. Eppson

One of the problems being studied is the factors which affect the rate of uptake of selenium from the soil by plants. In particular, the effect of the growth rate of the plant (as influenced by growth-regulating substances such as gibberellic acid) on selenium uptake is being examined. The effect of selenium on the uptake by selenium "indicator plants" of other elements as sulfur, molybdenum, tungsten, uranium and strontium will be determined by the use of radioisotopes. Information gained through basic studies of this type may be useful in work on the fission-product uptake by plants, including the search for accumulator species.

28. Title: Environmental Radiation
University of California at Los Angeles $165,644 Kermit H. Larson

This group conducted research in connection with Test Site Program 37 as follows:

1. Delineate fallout patterns of devices greater than 5 KT with respect to: (a) field and unit area radiation, (b) particle size, and (c) type of radiation, physical properties, solubility, etc.
2. Train participating personnel with respect to radiation measurements.

The 1958-60 program is divided broadly into five main areas:

1. Soil factors--influence of various native cations and anions on the availability of Sr and Cs. These ions are Ca, Mg, K, Na, Cs, and H; and Cl, SO_4, PO_4, CO_3, and NO_3.

2. Plant Factors - Influence of Ca on absorption of Sr-90 under short- and long-term cropping; influence of other factors such as soil type, organic matter content, pH, moisture, temperature, etc., on absorption of fission products by plants.

3. Biophysical relationships - A repeat of NTS program 37 of the Plumbbob series.

4. Radio-Ecological Relationships - Biological availability of selected samples from recent test series; plant productivity studies in selected areas of NTS.

29. Title: Absorption of Radioelements into Plants
Hanford Atomic Products Operation $66,000 F. P. Hungate

The activities of this program are divided between investigations of Hanford Operations problems and general studies of the fission product contamination of soils and plants. Reactor effluent has shown no effect on the yield, mutation rate, and radioactivity content of barley plants. The relationship

29. Title: Absorption of Radioelements into Plants (cont'd)

between gaseous I-131 concentration and absorption by plants was found to be linear, up to concentrations exceeding those to be expected from process losses or reactor disasters. The effects of substrate concentrations of calcium on the uptake of Sr-90 have been studied in nutrient solutions, acid soils, and alkaline soils. Anion effects were found to be almost as important as calcium concentration in affecting Sr uptake. Field experiments show no decreased availability of Sr-90 to plants since they were established in 1954. Also currently in progress are experiments on the effects of solubility factors on the availability of Sr-90, mechanisms of ion movement from soil to plant and within soils and plants, rates of uptake of short-lived radioactive waste products, and the availability with time of Zn65 in soils.

30. Title: Waste Disposal
Los Alamos Scientific Laboratory $31,000 C. W. Christenson

Current and recent investigations include the following:

1. A study on the effect of available soil calcium on the uptake of strontium by grass, alfalfa and lettuce.
2. Determination of depth of feeding zone of grass, alfalfa and lettuce by growing these plants in five foot deep plots with zones of soil spiked with cesium-137.
3. Effect of potassium and/or other soil nutrients on the uptake of cesium-137 by grass, lettuce and alfalfa. In conjunction with this project the results of the earlier work on effect of soil calcium on uptake of strontium-90 were confirmed.
4. Development of an analytical procedure for determination of available calcium in soils by use of calcium-45 tracer.
5. Determination of translocation of cesium-137 and strontium-90 applied to leaves of various plants in an attempt to determine relative amounts of fallout isotopes entering plants by foliar absorption.

31. Title: Ecological Research
Oak Ridge National Laboratory $225,000 E. G. Struxness & S.I. Auerbach

The primary purpose is to study the long-term effects of radioactive contamination of the environment, including:

1. Effects of radiation on ecological systems and their components, i.e., does radiation cause a shifting in populations?
2. What is the fate of fission products in the system?

Most of the research is being carried out in White Oak Lake Bed, where much of the waste materials have been dumped. The exposure approximates 0.5 roentgen per day for this area. Counts of kinds and numbers of birds and mammals in this area as compared to those in adjacent areas as controls may yield information about effects of radiation. The uptake of various fission products by forest trees, other plants, microorganisms and plankton, and the concentration of fission products in trees relative to that found in litter under the trees are studies. The release of various elements by soils and its relation to the soil properties are investigated. Current planning includes the consequences of controlled contamination of certain areas.

APPENDIX "C"

THE ATOMIC ENERGY PROGRAM IN OCEANOGRAPHY AND MARINE BIOLOGY

Prepared by I. E. Wallen, Aquatic Biologist
Division of Biology and Medicine
U. S. Atomic Energy Commission

Since before the first atomic device was exploded in the Pacific testing area, the Atomic Energy Commission has had an active interest in Oceanography and Marine Biology. When it became apparent that information was not available concerning the effects on the environment of large quantities of radiation such as that produced by atomic bombs, the Commission took steps to obtain information concerning the movement of radionuclides in the oceans and through marine animals. Although the science of oceanography has physical, chemical and geochemical as well as biological aspects, the emphasis within the Commission has been in projects that are ultimately biological in nature. Information is being sought that will elaborate the direct and indirect effects upon man of the presence of radioactive isotopes in sea water. The direct effects would be those related to the health of man and the indirect effects would be those related to the effect upon man's marine resources.

Within the last 10 years the number of reactors and other possible sources of accidental release of radioisotopes has been multiplied many fold. Most of the known radioactive isotopes of many elements have become important because of their possible release from research, production, test and power reactors; from ship and airplane propulsion plants; from chemical processing plants; or through activities of the thousands

of licensed isotope users. Since it is theoretically possible for radioactivity from any of these sources to get into the ocean, it is important that the Commission obtain the information necessary to evaluate such potential contamination.

Such studies have been underway since the earlier days of the Manhattan project. The Applied Fisheries Laboratory of the University of Washington was brought into the Plutonium project in 1943 during the construction of the Hanford facilities because of the complete lack of information about the events that might affect the Columbia River salmon and the river itself. Studies were initiated on chemical and radiation injury to fishes both by direct x-irradiation and by isotopic exposure of various fishes at different stages of development, including irradiation of the parents prior to fertilization of the eggs.

When marine surveys were needed in 1946 in connection with the Bikini operation the Applied Fisheries Laboratory cooperated in the project, obtaining samples of marine life for radioanalysis and measurements of radioactivity, both in the ocean and on land. This initiated a continuing series of biologic surveys which have formed an important part of every test operation in the Pacific. In addition, interim surveys are being continued of the land and marine life and of the oceanographic distribution of radioactivity.

The Applied Fisheries Laboratory has made many important contributions to basic marine radiobiology. Especially significant have been the recording of the concentration of radioactivity in plankton in 1946 and the demonstration of the salmon as a valuable animal for genetic study, with abnormalities appearing in successive generations

after parent exposure to doses as low as 25 r. Data on some 5,000,000 offspring of irradiated fish parents have been recorded. Also notable is the Laboratory demonstration of abnormalities of cleavage of the egg after doses as low as 13 r.

Vessels from Scripps Institute of Oceanography, from the Texas A&M College Oceanographic Institute, from the University of Miami's Marine Laboratory, from the Lamont Geological Observatory of Columbia University and from the Woods Hole Oceanographic Institute have gathered data to help in the evaluation of the biological effects of the experiments and to determine the fate of radioactivity in the oceans.

Since 1950 the U.S. Bureau of Commercial Fisheries has operated its Beaufort Laboratory in cooperation with the Atomic Energy Commission to study the uptake by many kinds of marine plants and animals of individual radionuclides from sea water.

During the last several years the Commission program has been diversified in its approach to the problems of Oceanography and Marine Biology. For the purposes of this presentation I should like to outline the existing AEC research program, using the headings given in the recent report of the National Academy of Sciences Committee on Oceanography which was exerpted in the Congressional Record.

Control and Monitoring - Although we recognize the need for an almost infinite number of samples of ocean water to answer all possible questions, the concept of the Commission has been to take a finite number of samples from locations that were determined to provide the maximum radiation and the average conditions. Prior to and following test activities, a grid of samples is taken to determine the location

of the mass of radioactive waters and its dilution to background levels. Studies are made around and in the area of any potential source of unusual radioactivity. Otherwise the world wide monitoring networks send in samples for frequent checking, as has been otherwise outlined to the committee. As is the case with test programs, the Commission will carry out detailed studies of prior and post conditions of the ocean in and near any project where atomic energy may be used for peaceful purposes, such as at the proposed Alaska Harbor project.

The Fiscal year 1959 funding in this area involves a total expenditure of approximately $255,000 at the University of Washington's Applied Fisheries Laboratory; the University of Hawaii's Marine Laboratory; the Shellfish Laboratory of the United States Bureau of Commercial Fisheries at Beaufort, North Carolina; the Vanderbilt Foundation of Stanford University; and, the Navy Department. Studies of uptake and residual radioactivity also are being made in cooperation with Taft Sanitary Engineering Center of the U.S. Public Health Service and with the Food and Drug Administration.

Estuarine and Coastal research - Along with the development of the uses of atomic energy for research reactors, for reactors to produce electric power and to propell ships, and for the production of isotopes for industry, the Commission has considered the various eventualities of release of radioactivity into the coastal environment. Studies have been undertaken with models and by direct experiments on the diffusion of radioactive nuclides in coastal waters, on the mechanisms of adsorption and flocculation of radiochemicals, on the

uptake of radionuclides by food web organisms, and on possible dilution and recycling of radioactivity in estuarine waters. One current project involves the development of possible counter measures for decontamination of harbor waters. This includes studies of flocculating agents to remove radioactivity from water and air masses surrounding a reactor powered vessel involved in a reactor accident. The work is being performed by the Armour Research Foundation and includes studies of dispersal using wake turbulence for discharging radioactive effluents from the nuclear ship. The U.S. Army Corps of Engineers Model Station at Vicksburg, Mississippi is doing special studies of radioactivity in major United States harbors using harbor models. A field study is now underway in New York harbor with both financial and operational cooperation with the Maritime Administration through the Coast and Geodetic Survey. The United States Public Health Service is making the necessary analyses for this project. Other such studies are planned.

The Texas A&M College is studying for us the adsorption of radionuclides to soil particles and their subsequent precipitation and possible recycling by bottom feeding organisms. The work of the Bureau of Commercial Fisheries Laboratory at Beaufort is also important in this regard as are several other smaller projects. The Commission provided funds for expenditures totaling about $230,000 for these projects during fiscal year 1959.

Research in Open Ocean - In some cases the research necessary to form a base line for atomic energy interpretations has not been completed and the Commission must do such research to establish the potentiality

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of certain operations. For example, although the Commission does not now plan to dispose of any considerable quantity of radionuclides at sea, the British are permitting one of their waste outfalls to empty into the Irish Sea and we are studying the potentialities of such disposal. In order to evaluate this problem we must have data on the normal currents of the deep ocean and on the length of time required for replacement of deep ocean waters.

The economic productivity of the oceans depends upon the interrelationships between the phytoplankton - zooplankton populations and their larger predators. Hydrographic conditions and bottom chemistry influence or control the plankton and their supply of essential nutrients. These relationships are only explainable after extensive simultaneous collections of plankton and of data on the chemistry, physics and geochemistry of a considerable portion of the ocean. The data may then be related to the distribution of radioactivity.

Here, as in few other research areas, the cooperation of various governmental and private agencies is of prime importance. The data, which is gathered by the Commission, supplements and complements studies on the oceans by the Office of Naval Research, the National Science Foundation, the Coast Guard, the Coast and Geodetic Survey, the Naval Bureau of Ordnance, the Maritime Administration, the U. S. Weather Bureau, the Bureau of Commercial Fisheries and other groups. Although each agency has a programmatic interest in certain kinds of oceanographic data there is sufficient overlap of interest in specific data that an informal group of agency representatives in Oceanography has met monthly for the past two years to coordinate the various agency interests in such a way as to obtain maximum value from the

data collected. Although the Commission's programmatic needs for information concerning the Oceanographic aspects of the test program have been adequately met by studies made primarily during the year of a test program and the year following, it is highly desirable that a more extensive survey be made of the physical, chemical, geochemical and biological conditions of the Central and Western Pacific. It is hoped that such a survey will be undertaken in the near future to provide information basic to an understanding of the currents, temperature, productivity, etc., which are necessary to adequately interpret the data gathered during a testing program or in the furtherance of a program for peaceful uses of atomic detonations.

The fiscal year 1959 level of Commission expenditures toward research of this nature is about $300,000. The research is being accomplished by the University of Washington Department of Oceanography, the Lamont Geological Observatory of Columbia University, the Woods Hole Oceanographic Institute, the Scripps Institute of Oceanography and the University of Miami Marine Laboratory.

Sedimentation - Certain kind of clays adsorb as much as 64% of the added radionuclides in areas where such clays are present. Montmorillonite, illite and kaolinite remove 64%, 62% and 53% respectively of Carbon-14 labeled complex organic matter from sea water. Adsorption of particles to other suspended materials in the ocean results in flocculation of much of the water borne radionuclides over a period of time. It is highly significant to determine whether these radiochemicals are permanently removed from the water or whether they may reappear. Studies must include such related problems as (1) an investigation of the nature of bottom deposits, (2) a determination of

the size and abundance of particles that might be available for adsorption, (3) a study of the clay-radionuclide interrelationship (physical and chemical) and, (4) studies of the capacity of marine organisms to strip radiochemicals from suspended or flocculated clays as well as to pass them through metabolic processes and the food web. Such studies are especially pertinent to coastal or estuarine areas but also apply to disturbances from nuclear detonations and dredging operations at any location.

The Commission is supporting various approaches to these problems at Scripps Institute of Oceanography, at Texas A&M College, at the University of Miami Marine Laboratory and in various inland laboratories where pilot studies may provide useful information. During fiscal year 1959 approximately $85,000 is being spent for these studies.

Effects of the Biosphere - As pointed out in National Academy of Sciences/National Research Council Publication #551, "The Effects of Atomic Radiation on Oceanography and Fisheries", the biological effects on the ultimate distribution of radioisotopes in the sea may be explained after studies of (1) the assimilation or adsorption of the elements by biological populations, (2) the vertical migration of organisms, (3) the horizontal migrations of larger animals, (4) the reactions of stationary animals in moving water systems, and (5) the cycling of radioisotopes through series of organisms.

If considerable amounts of fission products were to be added to the oceans, their ultimate distribution would depend not only upon the current systems and mixing processes which determine the exchanges of water between the deep and the surface layers, but also upon geochemical

and biological factors. Many of the elements present in a fission product mixture are insoluble in sea water; these would tend to settle out of the system and not approach equilibrium in the same way that would be expected for soluble materials. Organisms may be expected to accumulate various elements of the fission product mixture to a degree which will depend on the character of the element and the species of organism involved. Part of the accumulation within the organism would depend upon direct assimilation or absorption from the water; part would depend upon the ability of some filter feeding organisms to remove particles from the water; part would be determined by surface adsorption of certain elements to organisms, especially algae. Whether the particles be fission products or other organisms containing fission products, a filtering animal may incorporate these elements into living tissue at a higher concentration than that in the preceding medium. Studies by the Commission's Health and Safety Laboratory in New York have indicated that Plankton may attain an average concentration of fission products which is 470 times the concentration in sea water.

Once organisms have accumulated a radioisotope they may modify its distribution in a variety of ways. Following their death the organisms may be expected to sink towards the bottom and to carry with them those elements which are tightly bound within the organic or skeletal structures. While living, the organisms may make extensive vertical migrations within the water column, migrations which could transport radioisotopes from a contaminated layer to an uncontaminated zone. The materials which could be transported most effectively by living organisms during migration are those which reach equilibrium rapidly with the dissolved phase. In such a case an organism could

accumulate a considerable amount of an isotope while in contaminated water and release most of the accumulation by approaching equilibrium again in uncontaminated water.

Biological concentration and metabolism studies have been made on diverse marine organisms such as Tuna fish, sole, sharks, barracuda, mullets, (at least 50 other kinds of fishes), clams, oysters, scallops, snails, coral, sponges, nemerteans, crabs, sea cucumbers, sea weeds and plankton. Results are being obtained such as the following: (1) Tuna distribute Strontium-90 throughout their body tissues within a few hours but retain only 2% of the initial dose after 24 hours, (2) Eels under experimental conditions dispose of Strontium-90, Yttrium 90 and Iodine 131 quite rapidly, and (3) Foraminifera (tiny plankton organisms) show little or no accumulation of Strontium-90 or Cesium 137 but concentration factors up to 70 times, probably by adsorption, of Zinc 65, Cobalt 60, Ruthenium 106 and Zirconium 95 respectively have been indicated.

Research must be continued concerning specific effects of specific radioisotopes in the laboratory and in the field to determine the effect of radiation on man's resources, especially such problems as clarify the effect of the radioactivity on marketed products and on the ability of species to reproduce themselves.

Such studies of the Biological organisms involved in radionuclide transfer lead to inferences with regard to assessment of potential hazards from excessive contamination, but they may serve useful purposes as well. It may be that some use can be made of aquatic forms to concentrate radioactive contaminants in holding ponds. Biological

organisms may serve as indicators. Information concerning effects of radiation are also useful in the evaluation of potential hazards to humans as well as in studies of human diseases and cancer.

The Commission's support of research in this area is given to the Woods Hole Oceanographic Institute, the Bermuda Marine Biological Station, the University of Hawaii, the University of Texas and the University of Washington. The expenditure during fiscal year 1959 is approximately $170,000.

Genetic effects on Marine Organisms - During the early part of the Manhattan project in 1943 the University of Washington was asked to undertake extensive experiments to determine the effects of X-rays. These studies included more than 5 million fishes. The levels of radiation were studied that might be necessary to produce direct radiation damage and for production of many types of mutations and/or anomalies. On the basis of the results of these experiments the Commission was able to assess the probable effect of nuclear detonations to a sufficient extent to initiate the Pacific testing program.

It is desirable to carry out additional experiments with the genetics of marine organisms to check with existing genetics data for mice, fruit flies, mosquitoes and other more commonly used species. Some of the marine organisms offer excellent possibilities for such research since they have a relatively short life span and produce large numbers of offspring. Although the basic background research into the normal marine animal is in no way complete, the Commission has long indicated its interest in the genetic effects of radiation on all organisms and is prepared to support research in this area whenever

sufficient background research is accomplished. Although during fiscal year 1959 the Commission supported no work directly in this field, the Committee's attention is directed to the reports by Dr. Douglas Grahn where the Commission's extensive genetic studies are described. The results of these studies will be applicable to marine organisms for the most part.

Biological Field Experiments - As was the case in Japan, where the Atomic Bomb Casualty Commission is studying the exposed population, the opportunity to study populations of organisms exposed to testing devices in the Pacific has presented itself and studies of this nature have been undertaken. The complex situation in a marine environment makes such studies difficult, but the potentialities of this approach are expected to increase as we gain additional information from laboratory and field tests with individual species.

As discussed in detail in the National Academy of Sciences Committee on Oceanography report, Chapter 5, "Artificial Radioactivity in the Marine Environment", the addition of radioactive isotopes into small confined bodies of water can give approximations of oceanic effects on organism populations. The report also discusses the tagging of water masses in the ocean for the purpose of determining the rates of mixing in surface or subsurface waters and the interchange of radioactivity within the population of organisms.

Although some of the experimental area is above the surface of coral atolls, the University of Washington is investigating the biological effect of the Pacific testing program to organisms of Rongelap and Eniwetok Atolls. Twice annually a field party makes extensive collections of reef animals and plants to determine the extent of radiation

effect on these populations.

Pilot studies of the total effect of one radioactive isotope (Phosphorus 32) on the life of a pond and of a stream have been carried out by the University of Wisconsin and Michigan State University respectively. Similar work has also been undertaken on a modest scale by the University of Texas and the Bermuda Biological Station. Commission funds will be expended for this purpose in fiscal year 1959 to an amount of approximately $150,000

International Cooperation - The Commission has maintained a policy of cooperation with other governments throughout the nuclear testing program. For example, following the 1954 fallout incident involving the Fukuryu Maru and the Marshall Islands, the Commission sent two prominent biologists to Japan to assist with the evaluation of the possible contamination of tunafish. In 1956 a joint oceanographic survey of the waters and marine organisms of the equatorial Pacific was conducted by the United States and Japan. Samples and data were exchanged. Recently, between May and November, 1958, samples of tunafish were collected from fishery areas near the Pacific test site and these were analyzed at the University of Washington. The tuna were collected before, during and after the "Hardtack" series and only a few showed more radioactivity than would be expected from the normal potassium^{40} background radiation. In no case did the radioactivity approach the permissible concentrations for life time consumption of tuna by humans and in even these cases the isotopes present were relatively short lived. Only 1% of such

radioactivity was due to Cesium 137 and none to Strontium-90. Only one fish in 7 showed any Cesium.

The Commission is jointly sponsoring an International Congress in Oceanography at the United Nations Headquarters in September, 1959 to assist with the exchange of information. Assistance has been given to the Naples Zoological Station toward the procuring of research equipment in the field. In addition the research effort of the Commission has included foreign nationals of several countries for training under the Mutual Security Program. Cooperation by exchange of information in Oceanography has been especially notable with Norway, Japan and Great Britain.

Appendix D

RADIATION INDUCED LIFE SHORTENING AND ASSOCIATED EFFECTS

Prepared by Douglas Grahn, Geneticist
Division of Biology & Medicine
U.S. Atomic Energy Commission.

Almost at the outset of research in Atomic Energy, during World War II, a research program in radiation biology and medicine was established. This program has greatly expanded over the intervening 15 years and now stands as one of the larger research efforts in Biology and Medicine that is under full Federal support. One of the major efforts of the program has been to improve our knowledge of the late or delayed biological effects of whole body irradiations on the individual directly exposed. In the present fiscal year, these studies involve an expenditure of about $7,500,000. Nearly $3,000,000 is committed to the direct evaluation of radiation injury in man. A broad range of supporting studies on laboratory and domestic animals are funded by the additional $4,500,000.

While many pathological and physiological manifestations of chronic radiation injury can be measured, one frequently refers to the total expression of injury in terms of life shortening. Most of the AEC support of this research is at the major installations, since these programs require extensive animal facilities, considerable technical support and the ability to employ hazardous radiation sources. Several large experiments have also been concerned with the delayed effects of weapons quality radiation. A breakdown of the on-site program is attached. Some of the studies involving the toxicity and metabolism of radioactive elements are more directly investigations of the metabolic utilization, retention and excretion of isotopes. They are included in the summary since they yield vital information for the prediction and understanding of the life shortening effects of radioisotopes. A portion of these studies, however, are aimed at a direct evaluation of the life shortening and pertinent carcinogenic effects of specific internally deposited isotopes, such as Sr^{90}, I^{131}, Ra^{226} and others.

The off-site program tends to be limited to more specific aspects of the life shortening problems. Even here, however, the need for large facilities is apparent in that most of the contracts involve comparatively large sums and are placed in institutions where extensive facilities were either originally available or have been constructed for the purpose of the research program.

Every opportunity to make a direct study of chronic radiation injury in man is explored and followed up whenever practicable. The opportunities for such study are necessarily limited. In addition, human populations are subject to a distressingly high number of environmental variables that can confound the radiation effects under investigation. Consequently, carefully controlled experiments on laboratory animals are a vital adjunct to the program. These studies permit a careful separation of radiation effects from those produced by other environmental stresses. The use of short-lived laboratory animals also enables us to observe the whole spectrum of late effects in a relatively short time period and thus anticipate what can be expected in man. At the same time, the experimental analysis of the various effects affords the opportunity to develop an effective program on possible avenues of therapy and control.

A wide variety of animal species are employed in the life shortening studies. These are as follows: mice, rats, guinea pigs, dogs, burros, chickens, swine, sheep and monkeys. This diversity of experimental material is extremely valuable since there is no "man-like" laboratory or domestic animal upon which research efforts could be concentrated. Each species has its own attributes for radiation toxicity studies and each bears some degree of resemblance to what we know of human responses. The more extensive statistical studies are generally done with mice and rats, although at present there are several important experiments involving dogs and burros.

The total program has grown considerably from the modest efforts begun during World War II. As more information became available, the research became more critical and integrated concepts of radiation injury have emerged. In turn, these concepts have led to more precise experimental test procedures.

Significantly, the program has been a training ground for dozens of modern quantitative biologists. The major AEC installations are thus now characterized by teams of professional radiation biologists who organize and execute the long term studies on delayed radiation effects. Teamwork and a continuity of effort is essential to the program.

Research Activity

Studies in Man

The single biggest study is being carried out by the Atomic Bomb Casualty Commission which is administered by the National Academy of Sciences under contract with the AEC. Approximately 50,000 exposed Japanese, and a comparable number of unexposed, are being followed for a direct determination of the life shortening effect of the weapon detonations. A smaller number, 15 thousand, are being given a detailed clinical medical follow-up to ascertain disease morbidity rates and histories.

The time lapse since exposure has not been sufficient for most late effects to clearly emerge. This is encouraging since animal experiments suggest that considerable delay should occur and therefore man can not be looked upon as a uniquely radiosensitive species. However, leukemia has been observed in the survivors at a 2- to 3-fold greater frequency on the average than in unexposed Japanese, although the increase is statistically significant only at doses of 50 roentgens or more. Altogether, from 1947 through 1957, 83 cases of leukemia have arisen among the 63,000 survivors, while 10 cases appeared among 33,000 unexposed (beyond 3000 meters from the hypocenter). The highest number of new cases occurred in 1953, eight years post-exposure. New cases have declined in annual number since that time. Significantly, this rise and fall in response is also seen in mice subject to single doses of radiation, again suggesting that human experience will not be strikingly different from our laboratory animal experience.

A number of attempts have been made to define the dose-response curve for human leukemia from these data. The curves predict that from 0.5 to 2 new cases of leukemia will arise per million exposed persons per year for each roentgen of exposure. A good deal of uncertainty exists since the exact exposure doses are unknown and, curiously, the lowest of the five dose groups, approximately 2 roentgens, shows a lower incidence of leukemia than the supposedly unexposed group. It is this writer's opinion that the two highest dose groups, 500 and 1300 r, over-estimate the true effective tissue dose and that the dose-response curve is actually quite non-linear and accelerates with increasing dose. It also appears reasonable to assume that the annual probability of leukemia death continually changes with time and can be expected to progressively decline beyond 10 years post-exposure.

A similarly detailed long-term study is being carried out on the Marshall Islanders subject to local fallout in 1954 (Conard, BNL). Comparatively small groups are involved in this study. There are several hundred exposed persons, but only about a third of them received the highest dose in the incident, 175 roentgens. Most of them received a dose of only 14 roentgens.
These individuals, and a comparable number of unexposed Islanders, are given regular physical examinations and are also being spot checked for the presence of retained radionuclides. No untoward findings have appeared in the five years that have elapsed since the time of exposure, which is consistent with the Japanese experience.

Other studies of human groups are more specific in their experimental approach. American radiologists, particularly those who practiced before 1945, have been studied for both life shortening and cancer death rates, (Warren, New England Deaconess Hospital; Bacher, ANL). The results on life shortening are equivocal but leukemia deaths are consistently higher than among other medical specialists and general practitioners.

Another source of information is in the cancer death rate among children subjected to local irradiation in the neck region for therapeutic purposes (Hempelmann, University of Rochester). A definite increase in cancers of the organs and tissues of the neck is associated with an exposure history. Experimental studies on persons carrying above normal body burdens of radium are being done at Massachusetts Institute of Technology and Argonne National Laboratory. Many persons acquired a burden of radium as a result of an occupational exposure (watch dial painters) or a "therapeutic" injection; a practice that has long been discontinued. These individuals do not provide good direct measures of life shortening effects, but they provide data on the radium retention factors in man and a detailed picture of the pathologic changes in bone and associated tissues. Because of these human experiences, radium has become considered as a standard isotope to which other isotopes can be related. To date, the lowest retained burden that has shown evidence of minimal pathology in bone is about 0.4 microcuries of radium. Since radium emits, as it decays, a high energy particle, it is a more detrimental radioactive element than strontium 90, for example, but less detrimental than plutonium which tends to be retained in and damage the liver in addition to bone.

Preliminary studies are now under way on a rather large segment of the population of Northern Illinois, wherein the deep well drinking water contains relatively high levels of radium (Argonne National Laboratory). Some drinking waters contain radium levels approximating the presently accepted maximum permissible concentration of 4×10^{-8} microcuries per cubic centimeter of water (15.2×10^{-5} uc/gallon). Data on radium retention and bone tumor incidence are being sought.

Studies in Animals

Animal research in the general field of chronic radiation injury and mortality, or life shortening, is carried out under two different philosophies; experimental and theoretical. These are really not mutually exclusive approaches but rather define the methods and purposes of the research effort.

Experimental Research

Life shortening

Direct measurement

A primary interest at present is in the direct assessment of the life shortening effect of whole body exposure. This is frequently expressed as the per cent reduction of the mean lifetime of an irradiated group compared to the mean lifetime observed in an appropriate control or unirradiated group. The amount of life shortening is a function of total dose as well as the manner in which the dose is delivered.

When the radiation dose is delivered in a prompt or acute manner, as a single exposure, the per cent reduction of life for mice has been shown to be an accelerating function of dose (Sacher, ANL). In other words, as dose increases, the effect increases at a rate greater than would be calculated on a simple direct proportionality or linear hypothesis. This upward acceleration of effect is particularly noticeable in the dose range that produces acute mortality in the first month or so following exposure. It should be noted that the life shortening measures do not include the acute mortality, but are restricted to the animals surviving the acute radiation syndrome.

This non-linear relationship has been confirmed for doses in the acute lethal range (Grahn, ANL). Other data, (Storer, LASL; Gowen, Iowa State; Upton, ORNL) which cover the lower dose range, from less than 10 r to 600 r, are suggestive of an underlying non-linear function, but are not discriminating in this regard. In no instance, however, is there any direct evidence of an indifference or threshold dose.

When the exposure is protracted, that is, delivered at a low rate every day for the duration of the animal's life, the relation between life shortening and accumulated dose takes on a different form from that seen following single exposures. The relation is rather complex, if one observes effects up to 90 or 95% reduction of life. In the more limited range of practical concern, let's say for accumulated doses up

to 2000 or 3000 r, the relation is essentially linear and the reduction of life at accumulated doses above several hundred roentgens falls considerably below that observed for comparable single doses. Compared to the single exposure situation, it is not impossible for mice to accumulate under continuous exposure five times as much radiation while showing the same degree of life shortening (Grahn, ANL). At total dose levels below one hundred roentgens, there may be little difference between the reduction of life following either single exposures or low intensity continuous exposures.

For the mouse, a single dose of 100 r shortens life by about 5%, or roughly 30 days in 600. Available data indicate a variable life shortening effect down to 25 r. Below this, the single dose data are uncertain. Generally, however, a sufficient effect is noted below 25 r to suggest that an appropriately designed experiment could define this rather important portion of the curve.

Under continuous exposure, data on mice, rats, and guinea pigs indicate a definite life shortening effect of 3% or more at a dose rate of 1 r/day. This leads to accumulated doses of 400 r and above, depending upon the species. At 0.1 r/day, where the total dose may be less than 100 r, the presently available data are extremely variable. This is not unexpected since most of the effect is seen very late in life. One can predict, however, that mice would show a reduction of only 0.03 to 0.06 days per roentgen accumulated. This is about 1/100 of 1%. Unfortunately, no valid error of estimate can be attached to this prediction. Very small single dose exposures are likely to produce a similar amount of life shortening, but allowance should be made for the possibility that the effect could be up to 5 times greater than that produced by protracted exposure.

The experimental detection of life shortening at very low doses is essentially a statistical problem and extremely large experiments are required. Repeated efforts with moderate sized experiments have been and continue to be made. At present, low dose continuous exposure experiments are being carried out with mice and guinea pigs at Argonne National Laboratory and with dogs at the University of Rochester. Studies on the life shortening effect of a wide range of single dose levels are proceeding with burros (University of Tennessee); dogs (University of California, Davis; University of Rochester); rats (University of California, Berkeley; University of Rochester); and mice (ANL, BNL, ORNL, LASL, Jackson Laboratory, Iowa State College and others).

A frequent exposure condition employed in medical radiation therapy involves the delivery of a given total dose in a discrete number of brief but separate exposures. This situation can also occur under certain occupational or emergency conditions, and is experimentally called "dose fractionation." In theory, fractionation is expected to reduce the total effectiveness in a manner consistent with the previously noted reduced effect following a long continued exposure at low rates. This is approximately true when the number of dose fractions is 10 or 20 or more and the size of each fraction is 50 r or less. However, when a

given dose is divided into only two fractions, even though separated by a month, the life shortening effect seems to be essentially the same as when the total dose is delivered in one exposure (Kohn, University of California Medical School; Sacher, ANL). The dose per fraction in these studies was always several hundred roentgens or more and thus may not accurately indicate the expectations for two dose fractions of 50 r and below. In other words, size of dose fraction, number of fractions and the time interval between fractions, are all important factors in this problem. A great deal remains to be done in this area of investigation.

All of the preceding discussion has pertained to the life shortening effects of whole body exposure to external radiation sources. When the exposure is given to only a portion of the body the total effectiveness drops rapidly, although the amount of this sparing effect will vary with the tissues and organs exposed and size of dose. Preliminary studies with mice on this problem have indicated that for comparable doses the life shortening effect may be from one-half to one-tenth as effective for partial body exposure as compared to whole body exposure (Kohn, University of California Medical School). In general, abdominal irradiation is most nearly like whole body exposure and irradiation of the chest is significantly less detrimental (Noonan, University of Rochester). It should be emphasized, however, that there is no clear cut relationship between the effects of a partial body irradiation and a whole body irradiation that would permit prediction of effects under the former condition from what is known of the latter. The practical significance of this whole problem is realized when one considers that many of the survivors in Hiroshima and Nagasaki could have received extremely non-uniform exposures because of partial body shielding and much of the heterogeneity in those data may never be fully resolved.

Biological Variables

Almost all of the life shortening studies have been carried out on animals that were exposed when young adults, comparable to a 15 to 25-year-old human group. This is a logical procedure considering that the original motivation for toxicity studies was to improve knowledge of the occupational hazard. However, as it became apparent that the hazard could not be restricted to a small fairly homogeneous group, efforts were made to fill the need for information regarding age differences in radiosensitivity. Such studies are being done at the Universities of Rochester and California and at the Argonne and Oak Ridge National Laboratories. In general, these studies have shown that radiosensitivity is about twice as high for prepubertal animals as for adults and that sensitivity is fairly stable until middle age. Beyond middle age, radiosensitivity increases again in a nearly uniform manner. The available data are not in full agreement as to the details of the age trends, although they all definitely point to the early decrease in sensitivity that is followed by the stable period. The whole problem is under active investigation with reference to both single dose exposures and continuous exposure.

The two sexes also vary in the details of their response to whole body irradiation. The magnitude of the difference appears, however, to be a characteristic of the animal species involved. Mice, for example, show striking sex differences in the life shortening effects of single doses (Sacher and Grahn, ANL). The female is significantly more sensitive in terms of chronic injury and mortality, which is interpreted to be an expression of an endocrine system imbalance that results from the sterilizing effect of radiation on the female. Female mice are readily sterilized by 50 r. Other mammalian species are not as easily sterilized and consequently the adverse behavior of female mice may not be expected in other animals. Sex differences do offer, however, an indication of some of the more subtle physiological disturbances that follow irradiation.

A third biological variable concerns genetic differences in radiosensitivity. Studies to date on mice suggest that as much as one-half of the variation in response to radiation measured in a genetically heterogeneous group could be attributed to genetic factors. (Grahn, ANL; Kohn, University of California Medical School). In view of these data, even though they are restricted to limited observations on one species, it would seem reasonable to suggest that an allowance for this range of variability should be made in any prediction equations to be applied to genetically unknown or heterogeneous populations.

Genetic studies also provide experimental approaches to the investigation of mechanisms of radiation injury since genetic differences can be isolated and subject to close examination. One result of these studies at Argonne is the definite indication that a given single dose will produce a constant number of days of life shortening for genetically different mice that vary in normal life expectancy and radiosensitivity. Most of the differences that are observed are due to differences in the susceptibility to the induction of leukemia. If it can be demonstrated that basic radiation injury is independent of certain major physiological genetic variables within a species, then there is a more realistic hope that species differences may be resolved and predictions to man from experiments in animals can be done with some reasonable accuracy.

Physical Variables

The type and energy of the incident radiation is also a determining factor in any well defined relationship between life shortening and dose. This statement cannot attempt to present all of the facets of this problem since this involves the whole field of Radiological Physics as well as Radiation Biology. From an operational viewpoint, the comparative life shortening effects from external exposure to different radiation qualities is under active investigation at the major AEC installations; Argonne, Brookhaven, Los Alamos and Oak Ridge. The principal radiations of concern are x-rays, γ-rays, neutrons, mixtures of neutrons and γ-rays and weapons quality γ-rays, neutrons and mixtures thereof.

In a general way, the different radiations vary in their effectiveness as a function of the amount of energy transferred to the tissues for a given distance that the radiation travels. For example, high

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energy γ-rays transfer much less energy while travelling one centimeter than conventional x-rays, which, in turn, transfer less energy than neutrons in travelling the same distance. In a similar, but not directly proportional, manner, it requires a higher dose of high energy γ-rays to produce the same biological effect as from x-rays and, in turn, a lower dose is required for neutrons. These differences, when biologically measured, give a factor of equivalent effectiveness known as the RBE (Relative Biological Effectiveness). In terms of acute radiation lethality, and setting the x-ray (250 kvp) dose as 1.0, the γ-ray (Co^{60}) RBE is about 0.8 and the fission neutron RBE is between 1.0 and 3.0 with most estimates for small animals indicating a value of 2.0. The RBE measured for the acute lethal effects of single doses has without exception been noted to remain unchanged for radiation quality comparisons in terms of the life shortening induced by these single doses.

When a fast neutron exposure is delivered at a low rate over a long period of time, however, the RBE for life shortening appears to increase significantly above the usual values of 2 to 3. For low rates, on the order to 2 to 10 rad per day, fast neutrons may be 5 to 10 times as effective as Co^{60} γ-rays (Upton, ORNL).

The pathologic effects of internally deposited radionuclides is under intensive investigation (see attached research program breakdown). Directly or indirectly these studies provide information on the life shortening problem. At low body burdens, for example, 10 or 20 times the present maximum permissible burdens, the effects may be principally reflected in the tissue or organ in which the isotope is selectively deposited. Bone tumors and bone degeneration are among the main responses to such bone seeking isotopes as radium, strontium and plutonium. These manifestations along with unavoidable irradiation of the blood forming tissues in the bone which can lead to leukemia, have an associated general life shortening effect. The extent of this effect will depend upon the type of radiation emitted by the isotope, the energy of the radiation, the radioactive half-life and the long-term retention (Finkel, ANL and others). Almost every isotope requires direct experimental evaluation in order to obtain a realistic picture of its relative toxicity. A life shortening effect in mice is generally demonstrable at body burdens of 1 microcurie per kilogram.

Pathologic Changes

Life shortening is a very general, though operationally useful, expression of chronic radiation injury, and is a general manifestation of an almost infinite variety of pathologic changes in the tissues. However, with almost no exception, any changes observed are also found in unirradiated populations, and thus do not specifically identify radiation damage. The probability of death from many causes is increased after irradiation, though to a different degree for each cause.

Several pathologic changes in mice are readily increased in incidence by external irradiation. These are leukemia, aplastic anemia, certain tumors of the endocrine system and degenerative changes of the kidneys. Internally deposited isotopes, as noted above, produce damage selectively at the place of deposition. Detailed studies on the morbidity and mortality rates from

various tumors and degenerative diseases are being carried out at the Argonne and Oak Ridge National Laboratories. These studies will permit a more accurate description of chronic injury and will relate changes in death rate from specific causes to radiation dose, age and sex. Such data will permit a more precise prediction of the expected responses and their relation to general life shortening. At present, there is the suggestion from studies on mice subject to either single exposure or continuous exposure that leukemia may be induced by very low doses, though the probability is very small (Upton, ORNL; Lesher, AEC). Mammary tumors in rats appear to be induced in a frequency directly proportional to dose with no evidence for an indifference dose (Bond, BNL). The situation for bone tumors is uncertain because of difficulties in measuring the biologically significant dose in the bone structures, particularly from bone seeking isotopes.

In addition to routine morbidity statistics, careful attention is given to pathological changes at the cellular level. There is now evidence that irradiated animals show a progressive degeneration of the small blood vessels, the capillaries (Casarett, University of Rochester). Associated with this change is an increase in amount of the supporting tissues around blood vessels and throughout vital organs. The net effect of these degenerative changes is a reduction of blood supply and tissue nutrition that not only increases disease susceptibility but also predisposes the organism to a physiological systemic failure and premature death.

The biological basis of cell injury and subsequent life shortening is the subject of active investigation. A prevailing concept is that somatic or body cell injury is basically a genetic phenomenon. Gene mutations and chromosome changes are readily induced by radiation in all tissues, though we usually refer to these effects in terms of just the germinal or reproductive tissues. It has been suggested that the cell death and the long lasting residual injury that underlies chronic radiation mortality can be virtually entirely attributable to the persistent effect of radiation induced somatic mutations. Recent efforts to test this hypothesis (Curtis, BNL) have been interpreted as failing to substantiate the concept.

While a certain amount of diffuse physiological injury can certainly result, for example, from the circulating system changes noted above, these changes, themselves, could initially reflect direct genetic damage to the cells involved. This writer feels that the somatic mutation hypothesis for chronic injury is basically valid and deserves more extensive testing. A careful effort should be made, however, to separate systemic disturbances from genetic damage in somatic cells, since the former changes could be the final expression of initial somatic cell damage.

Theoretical Research

As indicated at the outset, experimental and theoretical research are not exclusive of each other. For the sake of clarity, however, it is better to consider those studies concerned with the theory of radiation lethality separately from the purely experimental studies. At present,

several theoretical approaches to the problem of life shortening are under examination. These may be entitled as (1), the theory of additive irreparable injury, (2) the statistical theory of physiological variation in radiosensitivity, and (3) the theory of radiation induced disruption of unique biological organization.

The first of these, the irreparable injury theory, described by Blair (University of Rochester), proved to be exceptionally stimulating to research in chronic radiation injury. Basically, this theory assumes that any radiation induced injury will be additive with all previous and succeeding radiation injury, and that the total amount of injury is a simple linear function of dose. The formulation assumes an exponential rate of recovery from immediate damage but that a constant proportion of this damage is irreparable. It is this irreparable component that is additive. It is also necessary to postulate that natural aging is equivalent to a linear accumulation of injury. Radiation induced irreparable injury then adds to natural aging as if to advance age by a predictable amount that would be proportional to dose. Formulations derived from these assumptions have been descriptive of some life shortening data but do not account for non-linear aging processes and age and dose dependent recovery rates.

The second theory, the statistical theory, derived by Sacher (ANL), also assumes an additivity of all radiation induced injury and natural aging, but is not restrictive with respect to recovery processes. The descriptive analysis of life shortening data then permits the recognition of different time and dose dependent processes, but the theory does not predict these processes. The analyses have shown, however, that specific fluctuations of a dose-response curve reflect experimentally measurable physiological variations in radiosensitivity that vary from one organ system to another with time and total dose. The theory has demonstrated the intimate relationship of the injury processes seen under continuous exposure with those characteristic of single dose exposure. This has permitted an economy of experimentation since more information per animal can be gained from continuous exposure techniques.

One outgrowth of these analyses has been to realize the value of applying standard actuarial statistical methods to life shortening data (Sacher, ANL). An extension of these methods to diverse injurious factors in the environment has also been made (Jones, University of California Radiation Laboratory), but this has lead to some oversimplifications. The actuarial approach -- the mortality rate analysis -- has indicated that life shortening effects can be broken down into a series of component parts that are not all simply additive to natural aging throughout the life span. Different tumors and degenerative processes occur at different ages and they do not all add up in a simple way to predict the ultimate life shortening in a consistent way from one dose level to the next. As a consequence, detailed pathology studies have increased in importance.

The third theory, the disruption of organization theory, also known as the information theory approach, has been employed by Quastler (BNL) and Yockey (ORNL). This theory comes at the problem from a more thermodynamic viewpoint. Biological systems are recognized as highly unique

in their organization but that this orderliness gradually breaks down with time until a lower level of order is reached which is incompatible with life. Radiation acts to increase the rate of approach to this lethal level. In a sense the theory yields analyses that are comparable to the actuarial statistical methods since both procedures are based on the recognition of an accelerating increase in mortality with age. Applications of information theory to the life shortening problem are really still in their infancy but should prove valuable by providing a fresh approach.

All of the above theories are presently more descriptive than predictive. However, they demonstrate that the state of our experimental knowledge is not fully adequate, and indicate where some of the deficiencies lie. Consequently, the final point of this discussion is reserved for that part of the research program devoted to the experimental research that directly asks the one question the theories emphasize, what is the rate of recovery from radiation injury and what are its controlling factors?

Recovery rate studies are being done in a number of laboratories (ANL, ORNL, LASL, University of Rochester, University of California, Jackson Laboratory). The usual method is the paired-dose technique. In this, a first sublethal dose is given, then, after various time intervals, a second dose or range of doses is delivered so as to produce a measurable amount of acute radiation mortality. As the time between the first and second dose is increased, the size of the second dose required to produce a certain amount of death, say 50%, also increases. This reflects the progressively declining residual injury of the first dose and measures the rate at which the animal recovers.

Recovery rates are being evaluated as they may vary with radiation quality, sex, genetic constitution, species, age, previous radiation history, size of initial dose and portion of the body exposed. Recovery rate in mice has already been shown to be a function of the size of the first dose; the greater the initial injury, the slower the rate of recovery. Other data suggest that recovery from neutron exposure is slower than from γ-ray exposure, but this seems to vary with the exact test employed. Genetically different mice have varying recovery rates which partially reflect their general level of radiosensitivity. Different mammalian species also vary in recovery rate. The rates vary with species to the extent that from less than 2 days to over 7 days is required for half of the initial injury to disappear. Man is presumed to have a slow recovery rate, possibly one to two weeks would be required for a 50% reduction of initial injury.

Partial body exposures indicate that injury induced in the chest region recovers more slowly than that in the abdominal region.

The question of age changes in recovery rate is presently under preliminary test. It is expected that the results will reflect the age changes in radiosensitivity previously described. Interactions between age and previous radiation history are to be investigated and should indicate the effect of accumulating radiation damage on recovery processes and their relationships to observable life shortening.

As the understanding of recoverable and nonrecoverable injury is increased, improvements in theoretical considerations will occur. Ultimately, a sound integration of the chronic injury and recovery patterns of diverse mammalian species should lead to accurate descriptive parameters of the life shortening expectations for human populations under various radiation exposures.

Recommendations

The research program in chronic radiation toxicity has always reflected the needs of the time, but concurrently, it has progressed steadily from the simple observational study to more complex investigations of physiological variables and their interactions with dose. As a natural growth process, more and more attention has been given to detailed statistical estimation and testing as well as the more complete definition of pathologic changes leading to death. The future program must extend this attention to detail and become more rigorous in its experimental philosophy.

Studies on the cellular and physiological aspects of chronic injury should be expanded. Life shortening studies should be more completely integrated with tests and hypotheses of tumor formation. In this light, the theory of somatic mutation as the basis of chronic radiation injury requires exacting demonstration and proof.

A good deal of interest is expressed in the possible parallelism between natural aging and radiation induced aging. A logically oriented search for such parallels is desirable. However, the point of departure should be from the irradiated animal, not from the normal animal, since our goal is to understand radiation induced injury.

Direct studies of irradiated human populations should be undertaken wherever statistically sound efforts can be deployed. An increased effort toward defining the exposure levels in human studies is imperative if quantitative testing is to be done.

Consideration should also be given to the possibility of executing several large scale studies involving tens of thousands of small laboratory animals. These could answer questions about dose-response curves at very low dose levels for both life shortening and tumor responses. Further studies involving the larger domestic animals should also be considered since their long life expectancy and large size would permit the detailed study of the pathologic physiology of individual animals for many years.

As a general philosophy, expansions in the chronic toxicity program should be through carefully conceived experiments designed to realistically evaluate the biological and/or statistical parameters in question. Because of the long-term nature of the studies, the maximum amount of information should be extracted and this can only be done through carefully designed experiments.

Conclusions

The primary studies on irradiated human populations have not gone far enough beyond the time of exposure to show many of the delayed effects that could be expected on the basis of our animal experience. The incidence of leukemia has increased significantly in the exposed Japanese, but the present data do not yet permit any change in the relation between total dose and leukemia frequency beyond that presented in 1957. It was suggested then that the probability of inducing a leukemia by single high intensity exposures was in the range of 0.5 to 2 per million men per roentgen in each year post-exposure. There is a strong indication that this probability may decline somewhat after 10 or more years. This early rise in leukemia in the absence of other overt pathology is not unlike the response of laboratory animals and indicates that man is not uniquely radiosensitive. The value of our extensive laboratory investigations for the anticipation of human responses is further substantiated.

The continued accrual and analysis of life shortening data in laboratory animals has confirmed the existence of markedly different degrees of effect following single dose exposure as compared to low dose rate continuous exposure. For the peacetime fallout situation, the life shortening in man may be predicted to be as low as 1/100 of 1% per roentgen accumulated on the assumption that the expected response of mice at very low doses can be simply extrapolated to man. Allowance should be made, however, for the possibility that the effect could be up to five times as great. This is a range for man of from 2 to 12 days per accumulated roentgen of whole body exposure or its equivalent. The uncertainty of this range is extremely high when referring to total doses of 25 r or less.

While much remains to be learned about how different exposure patterns reduce the life expectancy, it can be assumed that a series of short duration high intensity exposures, even to low total doses, could have a greater effect than noted above. The amount of increase in severity of effect should increase with size of the individual doses. Irradiation of one-half of the body, however, even when involving rather large doses, will have an effect only one-half to one-tenth that observed for whole body exposure.

Existing data indicate that young children may be more sensitive than adults to radiation induced injury and emphasize the need to minimize their exposure. It has also been indicated that long-term low rate exposure to fast neutrons may be 5 to 10 times as damaging as comparable exposure to lower energy x and γ-radiation.

The life shortening effect of the internally deposited radioisotopes also continues to be studied. Recent data from mice indicate that, on an equivalent weight basis, a retained burden of strontium-90 ten times the maximum permissible occupational exposure level for man produces a life shortening effect in the neighborhood of 2%. This figure is not inconsistent with expectations from whole body external irradiation, even though the dose from Sr^{90} is principally to the skeleton and surrounding soft tissues.

A number of recommendations for continued research have been made. Particular emphasis is indicated for the study of cellular mechanisms of chronic radiation injury. More exacting tests of existing and future hypotheses and concepts of chronic injury is also urged. Human studies should be undertaken when practicable but there is a definite need for improvement in our knowledge of the exact tissue and body doses received by such groups.

On-Site Research Program:

Toxicity of External Radiations:

Argonne National Laboratory	
X-ray and γ-ray toxicity	$ 356,000
Neutron toxicity	136,000
Brookhaven National Laboratory	
Radiation aging in mice	50,000
Radiation effects of medical significance (includes study of Marshall Islanders)	650,000
Los Alamos Scientific Laboratory	
Acute and chronic effects of different radiations	234,000
Oak Ridge National Laboratory	
Pathological effects of radiation exposure	255,000
University of California at Los Angeles	
Late effects of radiation on rats	54,000
University of California Medical School	
Late effects of partial and whole body irradiation	80,000
University of Rochester - Atomic Energy Project	
Effect of x-rays and nutritional state on radiation injury and recovery	46,000
Effect of x-rays on spermatogenesis in dogs	104,000
University of Tennessee - Agricultural Research Lab.	
External radiation studies with large animals	88,000

Toxicity and Metabolism of Radionuclides - Studies Pertinent to Life Shortening and Associated Effects

Argonne National Laboratory	
Toxicity of internal emitters	203,000
Radioelement metabolism in humans	369,000

Hanford Laboratories - Biology	
Fission product metabolism and toxicity (8 sub-projects)	$ 722,000
Los Alamos Scientific Laboratory	
Toxicity and retention of γ-emitting isotopes	18,000
Oak Ridge National Laboratory	
Dosimetry of internal emitters	169,000
University of California Radiation Laboratory	
Biological effects of internal emitters (3 sub-projects)	232,000
University of Rochester - Atomic Energy Project	
Chronic effects of Sr-90 in monkeys	46,000
Induction of tumors with radioactive agents	43,000
Biological effect of radium and other radionuclides (2 sub-projects)	71,000
University of Tennessee - Agricultural Research Lab.	
Fission product metabolism in farm animals	110,000

Off-Site Research Contracts:

Toxicity of External Radiations:

National Academy of Sciences - National Research Council Atomic Bomb Casualty Committee		1,925,000
A. C. Andersen	University of California	100,000
Effect of Radiation on work capacity and longevity of the dog.		
D. L. Wood	University of California	55,000
Age and vulnerability to x-rays.		
H. Sobel	Cedars of Lebanon Hospital	12,000
Studies on connective tissues of animals prematurely aged by irradiation		
J. A. Shannon	Dept. of Health, Education & Welfare	105,000
Studies on long range effects of radiation on human beings		

J. W. Gowen	Iowa State College Lifetime sickness and mortality and progeny effects resulting from exposure of animals to penetrating radiation	$ 117,000
J. Storer	R. B. Jackson Memoral Lab. Rate of recovery from radiation injury.	27,000
S. Warren	New England Deaconess Hospital Acute and chronic radiation injury	250,000
L. H. Hempelmann	University of Rochester Response to ionizing radiations in animals and patients	45,000
L. D. Carlson	University of Washington Physiological capabilities of the hematopoietic and other cell systems in mice exposed to low level chronic ionizing radiation	13,500

Toxicity and Metabolism of Radionuclides - Studies Pertinent to Life Shortening and Associated Effects

A. C. Andersen	University of California Effects of Sr-90 administered during the growth period of the dog.	125,000
C. E. Comar	Cornell University Fission product metabolism and response in laboratory and domestic animals	45,000
L. A. Barrer	New Jersey State Dept. of Health Epidemiological investigation of radium dial painters	70,000
V. R. Bohman	University of Nevada Range Livestock production adjacent to Nevada Proving Grounds	35,000
R. D. Evans	Massachusetts Institute of Technology Radium and mesothorium poisoning	145,000
T. F. Dougherty	University of Utah Toxicity studies of plutonium and other Radioactive substances in animals	325,000

Appendix E

STATUS REPORT ON RADIATION GENETICS

Prepared by Douglas Grahn, Geneticist
Division of Biology and Medicine
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The study of both basic genetics and radiation genetics continues to be one of the major efforts of the AEC biology research program. At present, it involves an annual expenditure of over $3,000,000. Approximately two-thirds of this investment supports work in AEC installations. This on-site program covers many phases of genetics but has a strong concentration of effort on the more pressing questions that are associated with atomic energy problems. For example, extensive studies are being carried out on the estimation of mutation rates in both sexes of a mammalian species (mice), the kinetics of radiation induced chromosome damage, and the mechanism of ameliorating induced genetic damage. Several installations, Brookhaven National Laboratory and the University of Tennessee Agricultural Experiment Station at Oak Ridge, also serve in both a research and service capacity regarding the application of radiation induced genetic variability for the improvement of economic crops.

The off-site program, carried on in about three dozen different colleges, universities and research institutes under 50 active contracts is also broadly distributed over the field of genetic investigations and contains a significant effort in the field of population genetics and human genetics. A list of the off-site research contracts and on-site programs is attached. The total program is subdivided into seven major categories of genetic research. Although any categorization has an arbitrary quality, it permits a more rapid survey of the research activity.

Recent Research Results

The Induction of Mutations by Radiations.

Several research results of the past few years have a particularly strong bearing on the immediate question of the genetic hazards to man of fallout radiation. A satisfactorily high proportion of the more cogent findings have been produced by AEC contractors, both on-site and off-site.

For many years it has been almost unequivocally assumed that the production of gene mutations is directly proportional to total radiation dose, regardless of the rate at which the radiation was delivered. In other words, it has been the expectation that a given dose would produce the same number of mutations whether this dose was delivered in a brief period of a few minutes or over a very protracted period of many years. This concept has been challenged by recent data on mutation production in the spermatogonia of mice wherein a 100,000 fold difference in dose rates has been tested for mutagenic efficiency (Russell, et al. 1958). Briefly, the test was this: male mice were exposed to total doses of cesium-137 γ-rays of 86, 516 and 861 r at dose rates of 10, 90, and 90 r/week, respectively. The yield of mutations produced in the spermatogonia was only one-fourth of that observed when similar total doses are delivered at approximately 90 r/minute. It should be emphasized, however, that at either high or low dose rates, the mutation yield remains linearly proportional to total dose. It is the factor of proportionality or slope of the

mutation vs. dose relation that is four times lower at low as compared to high dose rates. There is no evidence of a so-called indifference dose, that is, a dose below which no effort would be measured. In fact, cytological study of irradiated germinal tissues (Oakberg, 1958) indicates that cell death occurs at a measurably greater frequency after only 1 to 2 roentgens of exposure than in unirradiated tissues. This cell death, involving the spermatogonial cells (a predecessor cell of the ultimate germ cell, the spermatozoon), has been shown to result from damage to the genetic materials (Oakberg 1957).

The implications of these findings are several. From the practical viewpoint there appears the distinct possibility that the genetic hazard of very low doses of radiation delivered at extremely low dose rates, as in the case of fallout radiation, may be only one-fourth as great as previously considered. However, at this moment, it would be premature to recommend any relaxation of control over the limitation of genetically significant doses to the gonads. For that matter, a relaxation of vigilance would be extremely undesirable at any time. Nevertheless, we should take cognizance of the possibility that our assessment of the long term genetic hazard that stems from unavoidable radiation exposure may be significantly lower than earlier predictions, but would still be about four times higher than predictions based on Drosophila data for the spermatogonial cell (Alexander 1954).

An intriguing scientific aspect of the dose rate effect on mutation production concerns the concept that the mutation event is susceptible to some recovery-like process. Some portion of induced mutations may lack the quality of immediate permanency that was always implicit in the earlier concepts of dose rate independence.

It has been recognized for some years that a non-ionizing radiation, such as ultra-violet light, produces a certain type of genetic damage that can be prohibited from gaining final expression as a mutation (Zelle et al., 1958). In this instance, ordinary light provides the necessary energy for metabolic steps that reverse the process of mutation fixation.

The induction by ionizing radiations of simple chromosome breaks are directly proportional to total dose, but the production of chromosome rearrangement has been recognized as dependent upon dose rate (Lea, 1946). The mechanism here involves the probability of restitution of a chromosome break as a function of time after the event in combination with the probability that a second break will itself restitute or recombine with the first break. For example, if a radiation dose is given at a low dose rate, the probability of two breaks combining with each other to yield a rearrangement is much lower than if the same dose is given at a high dose rate. At low dose rates, there is a greater chance of restitution of a first break before a second break occurs, since the duration of the exposure may be sufficient to allow the first break to restitute. Ordinarily, from 30 to 40 minutes is considered the maximum time over which a break, that is capable of restitution, will remain open. Recent studies have shown that the restitution of chromosome breaks requires metabolic energy, the

radiation damage can be manifest in the rejoining mechanism, and that damage to the latter can be at least partially restored by provision of an energy source (Wolff & Luippold, 1955, 1958).

Until recently, the above findings for the reversibility of ultraviolet effects and the restoration of chromosome damage has not had its corollary with respect to the point mutation induced by ionizing radiation and presumed to be unassociated with structural chromosome damage. The dose rate effect on mutation production in mouse spermatogonial cells may involve a qualitatively similar mechanism to the above noted restoration processes. It was suggested by Russell, et al. that at least a portion of the induced mutations can be prevented from reaching final expression by means of some innate "repair" process. Failure of this process at high dose rates was then tentatively attributed to radiation damage on the restorative capacities themselves.

While direct evidence in support of the suggested hypotheses is lacking, data from other sources encourage the concept that the radiation induced mutation can be prevented from gaining fixation by either normal metabolic processes of protein synthesis or by experimental intervention of these processes. The data of Witkin (1956) and of Haas and Doudney (1957,58) on E. coli subjected to either ultraviolet or x-irradiation are pertinent in this regard. They have been able to show that mutation stabilization or fixation requires active protein synthesis. If a nitrogen source or amino acids are not available to the irradiated cell, then the mutation yield is depressed. An energy source is also required for this modification of mutation yield. Additional evidence is found in the recent work of Kimball (1958) employing a protozoan, Paramecium. His observations indicated that mutation stablization is a time dependent process related to the protein synthesis leading up to the final DNA formation that precedes cell division and the genetic segregation of a mutation. Thus, it has become increasingly apparent that the mutation process requires the successful performance of certain intermediate metabolic steps before the stabilization of a definitive gene mutation occurs. These intermediate steps, whose metabolic qualities are essentially unknown, do permit both normal and experimental intervention that can prevent some mutations from reaching final expression. The implications of these concepts to the problem of pre- or post-irradiation amelioration of induced mutations are obvious.

Certain additional information regarding the dose rate effect deserves mention. There is no apparent difference in the mutation yield at different dose rates when mutations are produced in mature sperm (Russell, et al., 1958). In addition, the mutation rate in sperm is about twice that for spermatogonia (Russell, Bangham and Gower, 1958). These are the expectations in light of our knowledge from Drosophila (Muller, 1954). In fact, the whole premise of dose rate independence had been based upon mutations induced in Drosophila sperm. DNA synthesis does not occur in mature germ cells and there is no gene replication or cell division. Since repair processes probably only occur in proliferating cells, a dose rate effect would not be expected in mature sperm. The mouse data therefore appear consistent with our data from lower forms with respect to both proliferating

and non-proliferating cells of the germinal tissue. However, since most mutations in mammals, including man, will undoubtedly arise in the stem or gonial cells, the mutation rates in the latter are the significant ones for evaluating the genetic hazards from fallout radiation.

The Effect of Mutations on Individuals and Populations

It is not enough to know merely that radiation will induce mutation, and that this will occur with some calculable frequency per roentgen of exposure. Some measure of the ultimate biological damage produced by the induced mutation is vitally necessary to permit an estimation of the overall genetic hazard. This is probably one of the most painstaking aspects of radiation genetics and can involve anything from the most delicate biochemical to the most complex mathematical techniques.

A gene mutation may be dominant in its expression, partially dominant or recessive. It may be lethal, sublethal or severely detrimental, mildly detrimental, near neutral, or, on very rare occasions, beneficial. The gene may act in a discrete, clear cut manner upon the individual's structure and/or function or may act in a more subtle nature in combination with many other genes.

The predominant number of mutations are detrimental and recessive, and ultimately, the detrimental gene is eliminated from the population by the death, reduced viability or reduced reproductive performance of the individual carrying the gene. Thus, an increased mutation rate will be reflected in an increase in individual distress.

Dominant mutations, if lethal, are eliminated immediately. Partially dominant mutations will generally be eliminated in the heterozygote, but they will persist in the population for a longer period by virtue of their incomplete expression. For example, if a partially dominant gene confers a 10% probability of death to its carrier, then the average persistence of the gene in the population will be 1/0.1 or 10 generations. These same considerations hold for a dominant gene that is not completely lethal in its expression.

Completely recessive mutations are only eliminated when they are in the homozygous condition. If lethal, the homozygous individual will not survive; if partially lethal or sublethal, only a portion of the homozygotes die. Complete elimination of the gene from the population would require thousands of generations, regardless of the severity of the effect, since the gene will persist in a hidden form in many heterozygotes. As an example, a recessive gene with a frequency of .01 will express itself in $(.01)^2$ or .01% of the population. The gene will exist in the heterozygous state in 2 (.99) (.01) or 1.98% of the population. For every death caused by this gene, there are 198 carriers remaining in the population. If the gene is not reintroduced by mutation pressure, then little by little its frequency will decline. If it is maintained in the population by recurring mutation then an equilibrium will be reached where elimination and mutation counterbalance each other. If the mutation rate is perpetually increased by a

given amount, the equilibrium level will be proportionately increased and the number of genetic deaths will increase. If the mutation rate is increased for only one generation, then the number of gene eliminations or genetic deaths will undergo a temporary rise and then gradually fall back to original levels. These latter considerations also hold for dominant and partially dominant mutations, although the time course of events will be more abrupt than in the case of completely recessive genes.

The foregoing brief description of the behavior of mutations has been described in detail by numerous authors (e.g. Wright, 1931; Muller, 1954; Li, 1955). In a sense these descriptions are greatly simplified but do provide a working approach to the problem. To put these into practice, however, requires intimate knowledge of the proportion of different types of mutations that will be induced by radiation.

Muller has pointed out that, in Drosophila, there may be 3 to 5 times as many detrimental mutations with small effects as there are lethal mutations. Lethal mutations, when heterozygous, reduce the viability of the individual about 4% to 5%, on the average (Stern, et al. 1952). Thus, recessive lethal mutants may behave as partially dominant genes and be eliminated predominantly in the heterozygous carriers. One new feature has emerged which still is not fully understood. A small portion of the lethals (ca 3-5%) may, when heterozygous, confer a small but nevertheless significant degree of improvement in viability (Stern et al., 1952).

Wallace (1957, 1958) has demonstrated in Drosophila that an irradiated chromosome, carried in the heterozygous state, improves viability an average 2.5% as compared to heterozygotes carrying the original unirradiated chromosome. The irradiated chromosomes, though untested for exact genetic composition, can be expected to carry a random array of recessive detrimental or even lethal mutations. These findings have led to controversy but have indeed stimulated a new interest in population problems. Actually, the results are consistent with newer concepts of population genetics which suggest that the "ideal" organism is heterozygous at more genetic loci than previously postulated (Lerner, 1954; Dobzhansky, 1955). Earlier concepts held that evolutionary forces strove to produce organisms that accumulated favorable genes in the homozygous state.

A discussion of the relative merits of the several hypotheses, their ramifications and supporting evidence cannot be done here. However, it must be indicated that at least one major misconception has arisen with respect to the effects of an increased mutation rate. The newer concept of population genetics, the balance hypothesis, demands that genetic variability be maintained at a high level. The most effective force that will maintain variability is the existence of a selective advantage for heterozygotes which can then lead to a balanced polymorphic genetic system. When this exists, a recessive gene, even though lethal when homozygous, will be held in the population. Thus, detrimental gene mutations might be considered a necessary, or at least acceptable, evil if a population is to maintain a maximum adaptive value. But, there is a price to pay, and this is not often given proper emphasis. A population can only maintain a high degree of heterozygosity and adaptive value through the

elimination of individuals carrying detrimental genes in the homozygous condition. For example, let us assume the original population was entirely homozygous (AA) at a given locus. A mutation occurs which is a recessive lethal, that is, all 'aa' individuals will die. If the heterozygote, Aa, holds a selective advantage of 20% over the original homozygous type, AA, then gene 'a' will be kept in the population and ultimately reach an equilibrium frequency of 1/6. In every generation, one individual in 36, $(1/6)^2$, will be of the 'aa' genotype and will die. In contrast, if mutation from A to a occurs spontaneously at the customary rate of 10^{-5} per generation and the genotypes AA and Aa are equal in value, then the equilibrium frequency of gene a will be the square root of 10^{-5}. The proportion of aa genotypes is the square of the gene frequency, or 10^{-5}, and only one in every one hundred thousand individuals is eliminated. In other words, a 20% selective advantage for the heterozygote will cause a 2800 fold increase in the death rate. Even a selective advantage of only 2.5%, as observed by Wallace, will increase the death rate by a factor of about 62. Obviously, a species cannot maintain genetic diversity free of charge, and any increase in the mutation rate will be associated with an increase in the frequency of genetic deaths. Theoretically, the population will not extinguish itself as long as the loss of homozygotes is counterbalanced by a selective advantage or increased reproductive performance of the heterozygotes.

With respect to mammalian populations, particularly man, there are many questions. To what extent does the heterozygote advantage control gene frequency in man? What proportion of the mutations will confer a disadvantage to the carriers? Even with the heterozygote advantage, is there a saturation point? Is there any correlation between the detrimental value of a homozygous recessive and the selective advantage or disadvantage of the heterozygote?

There are a few answers or examples of the type of information that can be sought. Allison (1955) has concluded that a recessive detrimental in man, the gene for sickle cell anemia, does confer a selective advantage to the heterozygote. In this case, the hererozygote shows a great resistance to malarial infestation, which is of selective value in the African populations that were studied. Approximately three-fourths of the recessive homozygotes fail to live to reproductive age and the heterozygote appears to have about 25% greater fertility than the homozygous dominant or normal gene.

It was recently suggested by Neel (1958) that many congenital malformations in man may be the segregants of genetically polymorphic systems involving a number of genes. This is inferred from the observation that the frequency of malformations at birth is very similar in a number of racial groups in spite of other striking differences. On the other hand, Stevenson (1959) has indicated that the majority of defects, about 58%, may be under relatively simple genetic control and that about 80% of these are manifested in the heterozygote.

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Other recent data on human populations, both Japanese (Schull, 1958) and American (Slatis et al., 1958), clearly indicate that mild forms of inbreeding, as in first cousin marriages, not only increase the frequency of congenital malformations but also markedly increase total infant and childhood mortality. Since inbreeding increases the probability that detrimental recessives will combine to form homozygotes, data from consanguineous marriages might be considered analogous to the condition of an increased mutation rate in a non-consanguineous population. Data on consanguineous marriages are not critical, however, with respect to the nature of the genetic control of malformations (Crow, 1958). Neel has suggested that interracial hybrids could be informative in the latter regard.

The large scale mouse genetics program at Oak Ridge has now observed over 200 radiation induced and spontaneous mutations combined. These are all recessive mutations that control a visible characteristic of the mouse. Evidence is becoming available on the overall manifestation of these mutations on the individual (Russell and Russell, 1958, 1959; Russell, Russell and Oakberg, 1958).

Significantly, of 92 radiation induced mutations tested, 71 or about 77% have proven to be recessive lethal. Many of the homozygous individuals die at or near birth. The particular test system employed in the Oak Ridge studies also permits the detection of mutations of minor effect. They make up only 5% to 10% of the total number, but they are generally non-lethal when homozygous.

The manifestations of the induced visible mutations, when in the heterozygous state, are generally not serious. Less than 3% have proven to be sterile. Reductions in viability and body size have tended to be associated with only one of the seven loci in the test system.

The offspring of the irradiated mice are certainly carrying new mutations at many loci other than the seven that are specifically screened. While these mutations are not producing visible changes in the heterozygous state, they nevertheless produce a generally detrimental effect. This is seen as a 4% reduction of offspring survival to three weeks of age (measured by size of litter) after a dose of 300 roentgens to the spermatogonia of the male parent. Nudzhin et al. (1955) have detected a similar magnitude of effect on litter size in both first and second generation offspring of irradiated males which substantiates the heritable basis for this detrimental response. Previously, Russell (1957) had noted in the progeny of irradiated males a slight but significant decrease in the mean life expectancy of 0.6 days per rep of neutron dose to the male parent. He presently reports (1959) on a preliminary basis a similar though less marked effect in the progeny of x-irradiated males.

Effects similar to those noted in mice have been detected in the progeny of irradiated chickens (Lerner et al. 1958 and unpublished data). In this instance, reproductive performance is reduced by the presence of non-visible detrimental mutations although some dominant lethal effects

are confounded. Performance changes are seen by an increase in age at sexual maturity, a decrease in egg hatchability and a decline in total eggs laid.

All of the above data on both mammalian and avian species are consistent with certain data from Drosophila but not consistent with all of it. Drosophila studies had predicted that there would be many more mildly detrimental genes induced than detectable lethals or visibles. This is indeed the case for the vertebrate species, even though the data do not permit quantitative calculations of the ratio of non-visible detrimentals to visible lethals. It is noteworthy that these detrimentals generally tend to show their effect in the heterozygote by reducing either survival value or reproductive efficiency. On this point, the vertebrate data, to the extent analyzed, appear inconsistent with some Drosophila data. Under certain specific experimental conditions, Drosophila can show improvement in viability when detrimental genes are heterozygous. Until this problem is clarified, it is appropriate to assume, as has Muller (1950 and on), that most induced mutations in man would manifest a detrimental effect upon the heterozygous carrier and thus would behave in the population according to the expectations for a partially dominant gene. Although detrimental genes which confer a selective advantage to the heterozygote will undoubtedly occur (see above example for sickle cell anemia), there is as yet no compelling reason to believe that the frequency of occurrence of the heterozygote advantage will be great enough to warrant serious modification of predictions based on the partial dominance hypothesis.

Prospectus for the Genetics Research Program

Idealistically, one might wish a set of prediction equations with which to calculate the genetic damage that would result from any occupational, medical, accidental or emergency radiation exposure. Nevertheless, even concentrating all of our efforts over the next five to ten years into this type of approach might not produce the necessary data. Further, such an approach is rather fatalistic, since it ignores the opportunity of developing techniques for modifying or ameliorating the genetic damage before it becomes a part of the genetic heritage. Rather, the program must recognize both the optimistic and the pessimistic aspects and should actively proceed to explore means of "therapeutically" reducing the hazard as it expands its knowledge of detrimental effects. In addition, a broad backup in basic genetic research should be provided as an integrating force.

In this light, and in cognizance of the preceding discussion of recent results, a minimum set of recommendations are offered.

I. Studies of the dose rate effect on mutagenic efficiency.

Expanded investigations are greatly needed to provide incontrovertible data on the reduced mutagenic effect of low dose rate radiation exposures. Additional dose rate and total dose variables need to be tested to determine if there is a critical dose rate, in combination with total dose, that cannot be exceeded without abruptly raising the

probability of mutation to the fourfold higher levels that have been established at the high dose rates. For practical considerations, most therapeutic and diagnostic medical irradiations are of a brief duration. Similarly, accidental or emergency exposures would be expected to be brief but at high radiation intensities. Even though the total dose over many years may be low, if the exposures are principally in short, high intensity bursts, the damage could be at the higher levels.

The necessary information can be obtained from several directions. Obviously, it should be directly measured in appropriate experiments with mice. Certain key experiments are also likely to be found in the field of Biochemical Genetics. Detailed knowledge is needed on the chemical kinetics of the mutation process, on the chemistry of gene replication and cell division and on the critically radiosensitive steps in the synthesis of genetic materials. Effective studies on the amelioration of genetic damage will require this detailed information. A sound theoretical understanding of the dose rate effect should also emerge from such studies of the chemistry of the gene.

Additional studies in Biophysics, particularly in Bioenergetics would be invaluable. These would provide more substantial data on the initial physical chemical events that are evoked by the absorption of radiation energy in living materials and provide clues as to the means of modifying or preventing the full expression of the damage.

II. Studies on the Genetics of Irradiated Populations.

A better understanding of what to expect in irradiated populations requires more complete data in three areas of genetics: (1) the more or less classical field of qualitative Mendelian Genetics; (2) the field of Quantitative Genetics, or the genetics of polygenic systems; and (3) Mathematical and Statistical Genetics. A close orientation to the problems in mammalian populations should be adhered to wherever practicable, although it is recognized that many theoretical concepts are best explored in a rapidly reproducing species, as Drosophila.

On the qualitative side, more complete data are required on the spectrum of induced mutations and their manifestations. What proportion will be lethal? What will be the average degree of dominance and will they be principally partially dominant? How many genes will have multiple effects? Will their expressions vary significantly with variation in the genetic background? An important question concerns the probability of a detrimental recessive gene conferring a selective advantage to the heterozygote. Is this to be expected on a wide scale in mammals? Is there a logical relationship between the degree of homozygous detrimental effect and the degree of heterozygous expression and whether the latter is advantageous or disadvantageous? Are expressions in the heterozygote more directly a function of interactions between non-allelic genes than between the members of the allelic pair? Questions of the latter type blend the qualitative problems with the quantitative.

Many genetically controlled characteristics do not permit simple genetic analysis. These traits are characterized by their variability of expression. In some instances this is due to an extreme sensitivity to environmental factors, although the trait may be controlled by only one gene or a few genes. In many instances, however, the genetic control rests in a large number of genes. These genetic systems have come to be known as polygenic systems, and control such traits as growth and form, intelligence, longevity, and, in domestic animals, such attributes as milk production, egg production, quality of wool, etc.

Evidence was presented in the previous section that there are detrimental mutations induced by radiation which alter longevity in mice. Data of this type are needed for as many traits as are susceptible to accurate experimental measurement and analysis. In small laboratory mammals, one can accurately measure mutation effects on longevity, growth rate and total growth, body length, bone length, and life time reproduction performance. In larger animals, many additional body dimensions can be studied along with life time measures of physiological activity of the cardiovascular, digestive and reproductive systems.

Mathematical and statistical genetics methods are basic to an effective analysis of the above mentioned quantitative traits. Of no less importance is the development of adequate mathematical genetic theory to describe the expected behavior of different types of mutant genes and gene systems in populations. The behavior and persistence of mutations will vary with the amount of inbreeding, the amount of assortive mating and with the extent of geographic and socio-economic isolating mechanisms. While there is extensive mathematical development for all basic genetic concepts, there appears to be a deficiency with respect to more modern hypotheses of population genetic structure. For example, a complete mathematical development is needed on the expected behavior of multiple allelic systems, polymorphic and classical and under normal and increased mutation pressures, with respect to random, non-random and interracial mating schemes.

III. Studies on Human Genetics

All of the questions put forth above are pertinent to attaining the ultimate goal of an accurate evaluation of the radiation genetic hazard in man. Most of the answers will have to come from laboratory and domestic animal studies, but as much genetic information as possible should be extracted from human populations. We recognize that the fundamental concepts of genetics are fully applicable to all organisms. It is in the more subtle and complex problems of gene interaction where different species are more likely to diverge in their genetic behavior and it is most difficult to interpret and characterize the genetic systems in the more plastic and physiologically complex species such as man.

One approach to these problems is through the comparative study of the offspring of consanguineous and non-consanguineous marriages. Observed changes in the frequency of detrimental traits and in the relative

proportions of different traits can aid in clarifying the significance and magnitude of the genetic component. Consanguinity studies also provide an estimate of the normal burden of detrimental genes and a means of estimating the spontaneous mutation rate.

Diverse human traits, both favorable and unfavorable, should be studied for the broad purpose of delineating the relative contribution of the genetic constitution and of the environment to character expression and control. These studies can obtain information from family differences, racial differences, geographical isolates, cultural isolates and twins. An effort should also be made to determine the change in selection pressures that arise from cultural innovation.

The genetics of malformation and defect demands particular attention. Close to 4% of all live born humans will manifest a physical or physiological defect. Many of these are known to be genetically controlled but only a few are probably under simple genetic control. Any conceivable means of studying the genetics of malformation should be exploited, e.g., consanguinity studies, family studies, racial and interracial studies, clinical medical and pathology studies and studies on the effects of prenatal environmental factors, maternal and paternal age and birth order. Although, as Stevenson points out, congenital defect frequency may not be the most important device for calculating radiation genetic damage, they do afford, because of their accessibility, a unique opportunity to study the diversity of genetic mechanisms operating in human populations.

Conclusion

The preceding summary and recommendations were rather specifically directed toward the immediate evaluation of the genetic hazard to man of occupational, medical, emergency or otherwise unavoidable radiation exposures. The summary was not an all inclusive review of radiation genetic studies. There are many additional studies which continue to develop the scientific base upon which operational considerations rest, since such considerations must be cognizant of existing genetic theory. It was indicated that radiation delivered at extremely low intensities, such as from fallout and natural sources, may be only about one-fourth as hazardous as previously calculated. However, it was not recommended that the newer figures be applied indiscriminately. Considerable corroborating evidence is required and much remains to be learned of the interactions between total dose and dose rate.

Evidence was presented to substantiate the generally accepted hypothesis that radiation induced mutations will exert some detrimental expression in the heterozygote. As a consequence of this expression, radiation damage will begin to emerge in the immediate progeny of irradiated parents, and the total genetic damage should be directly proportional to total radiation dose. It was recognized, though, that there is a definite probability that some detrimental mutants may actually confer a selective advantage to the heterozygous carrier. At present, it is not possible to predict the extent of this phenomenon in human

populations or exactly what it would do to predictions of expected genetic injury.

The present AEC research program in genetics is the largest integrated program in this country designed to evaluate the genetics hazards of radiation in both animals and man. It is strongly oriented towards the direct determination of both the radiation induced gene mutation rate and the behavior of mutant genes in populations. As a result, a very large fraction of the pertinent data necessary for an appraisal of the radiation genetic hazard for man has come from AEC-supported research.

In the past several years, a 20 to 25% expansion in this program has occurred. Among the recent new projects is one at Iowa State College designed to measure the quantitative effects of radiation-induced mutation on reproductive performance, growth and longevity in swine. While data of this type are in part available from the mouse, we require some assurance that the mouse is not yielding unique responses that have no relation to the expectations in man. A similar study on rats is under way at the University of Wisconsin. In this case more detailed statistical tests will be possible with respect to the induction of sex-linked lethal mutations, the accumulation of autosomal recessive lethal or lethal-equivalent mutations and the effect of inbreeding and outbreeding on the accumulation rate of all detrimental mutants.

In the field of human genetics a contract with the University of Pavia, Italy, has been negotiated for the purpose of comparing the incidence of genetic defects in the offspring of consanguineous and non-consanguineous marriages. An extremely detailed study of this type is also being supported in Japan through the University of Michigan and the Atomic Bomb Casualty Commission. A number of smaller off-site projects as well as expansion of the on-site program have been directed in the past several years toward a more accurate measure of the variation in mutation rates and the diverse expressions of mutant genes.

In order to activate some of the recommendations set forth above, informal discussions are being carried on with a number of geneticists. Unfortunately, there is a recognized shortage of trained manpower in many areas of genetics, particularly certain areas of mammalian, human and population genetics. Further, this type of research in mammalian systems is often time consuming and tedious. In spite of this a continued effort is being made to encourage research in the recommended areas. But until deficiencies in both manpower and facilities are overcome, it would be not only unrealistic but actually negligent to submit that every recommended research need could be filled in a matter of a few short years.

GENETICS RESEARCH PROGRAM
Off-Site Contracts

ANIMAL GENETICS

H. H. Plough — Amherst College — $20,000
Title: Genetic Effects of Acute and Chronic Low Level Irradiation with Cobalt-60.

Frances E. Clayton — Arkansas, Univ. of — $ 4,733
Title: Developmental-Genetic Study of the Effects of X-Ray Irradiation in Drosophila virilis and Bufo valliceps

Geo. Beadle — Calif. Inst. Tech. — $62,500
Title: Genetic and Cytological Effects of High Energy Radiation.

C. W. Edington — Florida State Univ. — $10,000
Title: Study of Gene and Chromosome Changes Induced by Ionizing Radiation in Drosophila melanogaster

Gowen & Stadler — Iowa State College — $117,000
Title: Quantitative Study of Lifetime Sickness and Mortality and Progeny Effects Resulting from Exposure of Animals to Penetrating Irradiation.

H. J. Muller — Indiana Univ. Found. — $34,995
Title: Influence of Radiation in Altering the Incidence of Mutations in Drosophila

H. B. Glass — Johns Hopkins Univ. — $14,000
Title: Action of Radiation and Other Mutagenic Agents - (1) in Inducing Mutations in Drosophila Females, and (2) in Controlling the Action of a Specific Gene Responsible for Suppressing Uncontrolled Growth

W. R. Lee — New Hampshire, Univ. of — $ 8,938
Title: Radiation Induced Viability Mutations in the Honey Bee.

M. Whittinghill — North Carolina, Univ. of — $ 9,288
Title: Study of Genetic Recombination as Influenced by Mutagenic and Non-mutagenic Environmental Agents

P. W. Whiting — Pennsylvania, Univ. of — $14,500
Title: Mutation Rates in Mormoniella

I. H. Herskowitz — St. Louis Univ. — $10,000
Title: Spontaneous and Radiation Mutagenesis and Mutability in Drosophila.

Mary L. Alexander — Texas, Univ. of — $12,500
Title: Effects of Radiations on the Genetic System of Organisms in Relation to Their Physiological and Biochemical Systems

PLANT GENETICS:

A. T. Wallace — Florida, Univ. of — $10,000
Title: Mutation in Research with Gamma Radiation at a Specific Locus in a Higher Plant.

R. S. Caldecott — Minnesota, Univ. of — $14,110
Title: Genetic Basis and Practical Significance of Mutations Induced in Oats and Barley with Ionizing Radiations.

Gardner & Hanway — Nebraska, Univ. of — $ 8,500
Title: Evaluation of Effects of Radiations on Quantitative Characters in Corn, Soybeans, and other Crops as Related to Breeding Improved Varieties: I. Corn Research
II. Soybean Research

W. C. Gregory — North Carolina State Col. — $19,030
Title: Radiation Genetics and Radiation Resistance in Peanuts

A. B. Burdick — Purdue Research Found. — $ 4,813
Title: Genetic Effects of Thermal Neutron Irradiation in Homozygous Tomatoes

W. R. Singleton — Virginia, Univ. of — $12,000
Title: Radiation Effects on Growing Plants

R. A. Nilan — Washington State Col. — $32,000
Title: Study of Factors that Govern Radiosensitivity in Plants

CYTOGENETICS:

W. Kenworthy — Brown Univ. — $ 6,300
Title: Radiation Effects on the Cytoplasm of Habrobracon Eggs

A. M. Clark — Delaware, Univ. of — $10,416
Title: Relation of Genome Number to Radiosensitivity in Habrobracon

A. V. Beatty — Emory Univ. — $ 8,600
Title: Studies of the Influence of Oxygen Level and Temperature on the Effects of Ionizing Radiation

H. B. Glass — Johns Hopkins Univ. — $28,000
Title: Effects of Ionizing Radiations on Gene and Chromosome Mutation Rates in Normal Human Cells in Tissue Culture

C. P. Swanson — Johns Hopkins Univ. — $11,340
Title: Modification by Supplementary Agents of the Rates of Induced Chromosome and Gene Changes

Demerec & Kaufmann — Long Island Biol. Assn. — $32,000
Title: Study of Spontaneous and Induced Genetic Changes in Mammalian Cells Grown in Tissue Cultures

R. C. King — Northwestern Univ. — $ 7,500
Title: Studies on the Radiation Genetics of Drosophila melanogaster Females

A. B. Griffen — R. B. Jackson Mem. Lab. — $18,000
Title: Occurrence of Chromosomal Aberrations in Pre-Spermatocytic Cells of Irradiate Male Mice.

N. H. Giles — Yale Univ. — $21,954
Title: Investigations on the Cytogenetic Effects of Radiations

N. H Giles — Yale Univ. — $23,000
Title: Radiation Effects on Mammalian Chromosomes in Tissue Cultures

POPULATION GENETICS:

T. Dobzhansky — Columbia Univ. — $16,548
Title: Population Genetics of Species of Drosophila

L. C. Dunn — Columbia Univ. — $25,000
Title: Studies of Mutations in Populations of Wild House Mice.

B. Wallace — Cornell Univ. — $19,492
Title: Investigation of the Genetic Structure of Populations

J. L. Lush — Iowa State College — $53,000
Title: Genetic Results of Irradiating Swine

W. P. Stephen — Oregon State College — $ 5,800
Title: Accelerated Evolution in the Alkali Bee Nomia melanderi through Irradiation

E. B. Spiess — Pittsburgh, Univ. of — $11,300
Title: Genetic Potential of Certain Populations of Drosophila persimilis from the Sierra Nevada of California

E. L. Green — R. B. Jackson Mem. Lab. — $30,493
Title: Quantitative Population Genetics of Mice Under Irradiation

W. S. Stone — Texas, Univ. of — $45,540
Title: Research on Direct and Indirect Effects of Radiations on the Genetic Systems of Organisms

A. B. Chapman — Wisconsin, Univ. of — $21,000
Title: Genetic Effects of Cumulative Irradiation in Rats

BIOCHEMICAL GENETICS:

F. J. Funk — Biochemical Research Found. — $19,870
Title: Search for Antimutagens

W. K. Baker — Chicago, Univ. of — $15,000
Title: Genetic Functioning of Heterochromatin

D. S. Grosch — North Carolina State Col. — $ 7,140
Title: Genetic and Developmental Effects of Ingested Radioactives in Habrobracon

E. S. Russell — R. B. Jackson Mem. Lab. — $27,500
Title: Attempt to Delineate Inborn Anemias in Mice

C. O. Doudney — Texas, Univ. of — $20,400
Title: Role of Nucleic Acid in Amino Acid Incorporation into Protein and in Enzyme Synthesis and Genetic Implications

D. M. Bonner — Yale Univ. — $26,500
Title: Relationship of Genes to Biochemical Reactions in Neurospora

MICROBIAL GENETICS:

T. M. Sonneborn — Indiana Univ. Found. — $26,000
Title: Cellular Heredity in Paramecium

J. B. Clark — Oklahoma, Univ. of — $10,200
Title: Cytology and Genetics of Radiation Resistance in Bacteria.

C. C. Lindegren — Southern Illinois Univ. — $12,000
Title: Effects of X-Rays and Ultraviolet Radiations on the Multiple Manifestations of a Gene Together with Genetical Analysis of the Radiation Induced Variations and Effects of Extracts From Unirradiated Cells on the Repair of the Genotypes of Irradiated Cells.

O. Wyss — Texas, Univ. of — $ 6,000
Title: Genetic and Biochemical Effects of Radiation on Bacteria.

HUMAN GENETICS:

J. V. Neel — Michigan, Univ. of — $76,635
Title: Development of Information Concerning (1) Human Mutation Rates (2) Accumulation of Deleterious Recessive Genes in Human Populations, and (3) Manner of Action of Selective Factors on Both Contemporary & Primitive Human Populations

A. A. Buzzati-Traverso — Pavia, Univ. of — $20,000
Title: Mutation Rates and Mutational Loads in Man

GENETICS RESEARCH PROGRAM
On-Site Programs

ANIMAL GENETICS

Argonne National Laboratory -

D. Grahn — $40,000
Genetics of Radiation Sensitivity

H. Slatis — $20,000
Induction of Recessive Lethal Mutations in Mice

Oak Ridge National Laboratory -

D. Lindsley, et al. — $142,000
Radiation Genetics of Drosophila

W. L. Russell, et al. — $600,000
Genetic Effects of Radiation in Mice

R. C. von Borstel, et al. — $61,000
Radiation Induced Dominant Lethal Mutations

University of California Radiation Laboratory -

C. Stern — $30,000
Radiation and Mutation Rate

University of Tennessee - AEC Research Lab -

R. L. Murphree — $75,000
Radiation Effects on Reproductive Functions in Farm Animals

PLANT GENETICS

Brookhaven National Laboratory -

J. L. Brewbaker — $70,000
Effects of Radiation on Self Sterility in Plants

H. J. Curtis — $30,000
Radiation Mutation in Plants

S. Shapiro — $45,000
Induced Beneficial Mutations in Plants

H. H. Smith — $100,000
Radiation Genetics in Plants

A. Sparrow — $120,000
Cellular Radiobiology in Plants

University of Tennessee - AEC Research Lab. -

T. S. Osborne — $55,000
Plant and Seed Irradiation

CYTOGENETICS

Argonne National Laboratory -

B. Nebel — $30,000
Radiation Effects on Chromosome Structure

Brookhaven National Laboratory -

D. Steffensen — $30,000
Molecular Structure of Chromosomes

Oak Ridge National Laboratory -

M. E. Gaulden, et al. — $60,000
Insect Cytology and Genetics

D. Schwartz, et al. — $60,000
Cytogenetics of Corn

S. Wolff, et al. — $60,000
Radiation Induced Chromosome Breakage

BIOCHEMICAL AND PHYSIOLOGICAL GENETICS

Oak Ridge National Laboratory -

R. F. Kimball — $96,000
Modification of Mutation Induction in Paramecium

MICROBIAL GENETICS

Argonne National Laboratory -

H. Kubitschek — $25,000
Induction of Mutations in Bacteria

E. L. Powers, et al. — $50,000
Radiation Sensitivity in Microorganisms

Brookhaven National Laboratory -

M. Levine — $30,000
Genetic Studies with Bacterial Viruses

Oak Ridge National Laboratory -

D. R. Krieg, et al. $60,000
Induced Mutation in Bacterial Viruses

F. J. de Serres, et al. $125,000
Radiation Induced Mutation in Neurospora

POPULATION GENETICS

No major programs

HUMAN GENETICS

Argonne National Laboratory -

H. Slatis $20,000
Descendants of Irradiated Women

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RESEARCH IN MOLECULAR BIOLOGY

APPENDIX F

By Leroy Augenstine, Biology Branch
(with the help of John Spikes and James Liverman)
Division of Biology and Medicine, U. S. A. E. C.

It is becoming increasingly apparent that we must expand our research in radiation biology at the cellular and molecular level. Only when we fully understand radiation effects at these levels can we hope to develop effective protective and remedial treatments. For reasons of practical necessity, much of the past effort of the Division of Biology and Medicine has been concerned with two very critical problems in radiobiology: (a) improving the physical measurements of the dose absorbed from both external radiation sources and internally deposited radioisotopes; and (b) quantitatively determining the biological changes (such as mutations, tumor formation, cataract formation, death, etc.) which appear hours, days, weeks, months or even years later. However, the accumulating knowledge from these studies has demonstrated that even in cases where we have good measurements of the dose we can not precisely predict the extent of the resulting biological change nor the exact time of its onset. This is particularly true when more than one kind of radiation is involved, as in the case of fallout.

Part of this uncertainty in predicting radiation damage results from the generally recognized variability of biological material. However, the main difficulty arises because there are numerous features of the radiation other than just the amount (dose) absorbed which affect the extent of radiation damage. These include: (1) the relative amounts of the different kinds of radiation involved, i.e., alpha, beta, gamma, or neutron; (2) the duration of the radiation exposure; (3) the oxygen content and metabolic level of the organism irradiated; and (4) the amount of radiation absorbed in different regions of the organism--in particular, regions

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which may have received no radiation at all. The relative importance of the individual features depends upon the biological effect being considered. This is of course not surprising because individual biological changes--such as those named above--are undoubtedly initiated by different biochemical events. Thus, although we still need refinements in many of our methods of measuring dose, we can not expect to completely solve the problems connected with radiation damage by achieving even infinite precision in our physical measurements.

As this fact has become more obvious in recent years, we have concentrated a larger fraction of our effort in more fundamental studies of the biophysical and biochemical effects of radiation. Thus, approximately $5,000,000 or 14% of the current research support provided by the Division of Biology and Medicine deals in some way with the area of Molecular Biology. This program is summarized in the following table. Its aims are to provide more intimate knowledge and understanding of the variety of cellular and sub-cellular changes produced so as to greatly improve our accuracy both in predicting the time of onset and the extent of radiation effects as well as prescribing necessary therapeutic measures.

SUMMARY OF RESEARCH SUPPORT IN MOLECULAR BIOLOGY

Subject Area	No. of Projects	(total)	Support in Thousands of Dollars	(total)
1. Biophysics		12		454
energy absorption and stability	5		305	
energy movement	7		149	
2. Biological and Physical Chemistry		128		2387
molecular effects of radiation	29		576	
molecular structures	23		784	
molecular biosynthesis	76		1027	
3. Cellular Physiology		129		2309
metabolism	96		1765	
permeability & electrolyte behavior	19		370	
biochemical genetics	14		174	
Total		269		5150

As can be inferred from the categories listed in this table not all of our supported research projects deal with studies of direct radiation effects per se. Rather, a large fraction are concerned with details of normal cell functioning. The efforts of many investigators have made it obvious that the changes in biochemical molecules and processes occurring in cells damaged by radiation are often very subtle. This is particularly true for the low levels of radiation encountered in fallout situations. Therefore, we have found it essential that companion studies of normal cellular processes be performed so that the variations produced by radiation can more readily be recognized and understood. Many projects serve the dual role of providing information necessary for radiation studies and at the same time furthering the beneficial applications of atomic energy.

From our past biophysical and biochemical studies it is known that as much as one million roentgens are required to produce appreciable "inactivation" of a specific biochemical in either the dry state or in a solution containing a number of other biochemicals--such as would be present in a cell. Yet, one thousand roentgens or less may be adequate to kill a significant number of some organisms or individual cells. Numerous explanations of this thousand-fold disparity have been advanced and are under investigation; for example,

(1) radiation destroys certain critical cellular components of which there is only "one-of-a-kind" per cell; or

(2) radiation-produced disturbances in the delicately balanced cellular metabolism become amplified; or

(3) radiation either produces poisonous products or else modifies the internal structure and cellular wall so as to allow necessary compounds to leak out or poisonous compounds in; or

(4) the mechanisms of energy-interchange within biological systems is such that absorbed energy is "funneled" to critical sites.

We cite the following fairly detailed examples of our research areas in which direct radiation and fundamental studies have been combined to evaluate the above potential explanations, as well as many others.

a) Chromosomes and their constituent "genes" are an example of critical cellular components of which there are normally only "one-(or two)of-a-kind" per cell. There is now fairly convincing evidence that radiation-induced genetic changes are the result of alterations in the deoxyribose nucleic acid (DNA) of the chromosomes. Some alterations are associated with gross aberrations involving whole chromosomes or large portions of them. Others which involve more subtle changes within the "gene" itself are called "point mutations." Further, it appears that DNA specifies the formation of ribose nucleic acid (RNA) and RNA then participates in protein formation. The proteins through their ability to catalyze chemical reactions control cellular metabolism so that eventually they are involved in duplication of the DNA incorporated into new chromosomes, thus completing the cycle DNA $\longrightarrow$ RNA $\longrightarrow$ Protein $\longrightarrow$ DNA.

Radiation received during that portion of the cell lifetime prior to the protein $\longrightarrow$ DNA part of the cycle is reportedly the most effective in initiating damage. However, under certain conditions appropriate treatments can alter the number of aberrations and "mutations" which are eventually expressed. These treatments include: the use of drugs to delay or depress protein and DNA synthesis; changes in the nutrients available to the cells; addition of metabolic inhibitors; administration of bursts of heat; changes in the water and oxygen content of the irradiated cells, and exposure to red light of a wavelength comparable to that which is

instrumental in triggering such diverse biological events as plant growth, the moulting of birds, shedding of hair by cows, etc. The number of genetic changes can also be altered by deficiencies in trace minerals.

Present evidence indicates the most likely event leading to an aberration is a "break" in the chromosome. Many of the treatments listed above undoubtedly act by either promoting or inhibiting the rejoining of the broken ends. Some may also affect the actual number of breaks produced. Other mechanisms which could lead to genetic changes are discussed and summarized in a table in the next section.

In order to better understand and expand the above information with the ultimate aim of improving our control and repair of genetic damage, we now provide approximately $1,300,000 for research aimed at unraveling the specific steps involved in the DNA → RNA → protein → DNA cycle and how radiation disarranges it. These include studies ranging from the synthesis of the building blocks for DNA, RNA and protein to the development of the most exacting tests for detecting subtle molecular changes.

The genetic effects produced by the decay of radionuclides incorporated directly into chromosomes may occur in at least three ways: (i) The "transmutation" of the decaying nuclide to a different atom changes the chemical composition of the chromosome. (ii) The decaying nuclide will "recoil" to compensate for the particle (or photon) ejected. This can cause a permanent displacement of that atom plus others and potentially a change in structure. (iii) The ejected particle (or photon) can produce damage, according to the mechanisms discussed for other sources of radiation. It is to be emphasized that radioisotopes incorporated into chromosomes will be retained by the organism almost indefinitely because the chromosomes maintain their composition relatively intact over many cell generations. The possibility that carbon-14 from fallout might be

involved in transmutation effects has been discussed by M. R. Zelle in his memorandum entitled "Statement on Biological Hazards of Carbon-14" submitted to the Joint Committee.

Tritium (in the form of thymidine) incorporated into chromosomes during DNA synthesis produces fragmentation at the first anaphase, 10 hours later. It is estimated that somewhere between 3 and 30 rads per hour, absorbed within the individual spherical nuclei from the decaying tritium, will produce chromosome fragments in 50% of the cells in Tradescantia root tips (D. Wimber, Proc. Nat. Acad. Sci., in press). Particularly pertinent to fallout considerations is the recent observation that strontium-90 can be incorporated into chromosomes (D. Steffensen and L. LaChance, unpublished preliminary results). The concentrations required to produce genetic changes are now under intensive investigation.

(General references: Radiation Biology, McGraw-Hill Co., New York, ed. A. Hollaender (1954) and Mechanisms in Radiobiology, Academic Press, New York, ed. A. Forssberg and M. Errera (1959).)

b) One group of projects, in which only selected portions of cells are irradiated with highly localized beams, provides information about many potential explanations of cellular damage. For instance, these techniques have been adapted to study the genetic changes mentioned in the previous section. In general, the procedure has been to determine how exposure of a restricted cell component to either ionizing or ultraviolet (UV) radiation disturbs the normal steps in the duplication of chromosomes and their distribution into "daughter cells." From an understanding of the control exerted on cell division by individual cell components the importance of each in producing radiation damage can be assessed. As mentioned in the previous section, "breaks" are undoubtedly the most common form of aberration and are probably initiated prior to the beginning of cell divi-

sion, that is, in interphase. Details of other pertinent effects produced during cell division are listed below. (R. Zirkle, Advances in Biological and Medical Physics, Vol. 5, 103-146 (1957))

Paling - If only a restricted portion of a single chromosome is irradiated with a sufficient dose of UV or protons, that region becomes "pale" when viewed with either visible or UV light. The loss in density is proportional to the total dose delivered but does not develop if the whole chromosome set is exposed. The paling apparently represents a loss of nucleic acid from a protein backbone which remains intact. However, in the case of UV, the initial absorption of the radiation energy responsible for this loss very likely occurs in the protein.

Stickiness - When doses insufficient for paling are absorbed in localized regions of the chromosomes, they will "stick" together when normally they should separate during cell division. This aberration can result in an incomplete set of chromosomes in one of the daughter cells involved. Similar effects can result from destruction of a centriole, spindle or kinetochore, all of which are involved in separating the individual members of each chromosome pair during the anaphase portion of cell division.

Spindle - Its destruction is an indirect result of irradiation of the cytoplasm and not of the spindle itself. In fact, irradiation of the cytoplasm of a closely-joined sister cell can suffice. The amount of ionizing radiation required for this effect varies greatly depending upon the type of cell involved. Thus this effect may contribute significantly to radiation damage in some cases.

Kinetochore - In contrast to the spindle, the kinetochore (the point of attachment of the spindle to the chromosome) is destroyed by radiation absorbed directly. Its destruction leads to a random, uncoordinated

drifting of whole chromosomes rather than the usual separation, at anaphase, of the individual chromatids.

Dosage values for the above effects produced during cell division are combined with data for the number of "breaks" produced per unit of dose absorbed during interphase. Unfortunately some of the data are only accurate within a factor of two and further, we do not have complete data for the five types of effects listed, or for a given type of cell with only one kind of radiation, nor for exactly identical irradiation conditions. Therefore, until more complete data are available it is to be emphasized that this table is only meant to give a very general idea of the relative importance of each type of effect in producing radiation damage.

RANGE OF DOSAGES REQUIRED TO PRODUCE DIFFERENT CHROMOSOME ABERRATIONS

Effect	Type of Cell	Radiation	Dose Required to Produce an Effect in 50% of the Cells	
Breaks[a]	Human fibroblast	X-ray		40 r
Breaks[b]	Human kidney	X-ray		165
Breaks[c]	Tradescantia microspores	X-ray		150 - 300
Spindle destruction[d]	Trillium microspores	X-ray		150
Stickiness[e]	Salamander heart	protons	3×10^{-8} ergs/μ^3 of irradiated chromosome	300
Kinetochore destruction[e]	Salamander heart	protons	10^{-7}	1000
Paling[e]	Salamander heart	protons	4×10^{-5}	400,000
Spindle destruction[e]	Salamander heart	protons	0.2 ergs/cell	2×10^9

(a/ T. Puck, J. Cell & Comp. Phys., 52 Supp. 1, 287 (1958); b/ M. Bender, Science 126, 974 (1957); c/ N. Giles, Radiation Biology, McGraw-Hill Co., New York, ed. A. Hollaender, p. 713 (1954); d/ A. Sparrow, Rad. Res., 1, 229 (1954); e/ R. Zirkle, unpublished results in preparation.)

Companion experiments are now in progress to determine where in the cell various portions of the DNA → RNA → protein cycle are conducted. Also under investigation are the disturbances produced in cell walls and inner cell membranes by these focused beams.

Another technique used for the irradiation of specific cell components is to break open cells and then isolate pure preparations of the component. These can then be irradiated and effects observed. For example, the details of radiation effects on the cell structures termed mitochondria (which carry out certain of the energy-producing reactions in cells) can be studied in this way. Similar studies have been carried out with the green chloroplasts of plants, the cell structures which absorb light energy and carry out photosynthesis. This technique should prove even more useful in the future for studies of the type described in the next section since it requires relatively simple research facilities.

c) There are two obvious factors that must be considered in assessing the contribution to the overall radiation damage of disturbances induced in the cellular metabolism. The first is the extent to which "normal" metabolism can be altered before the cell is killed. At least 96 projects, amounting to about $1,765,000, represent our continuing effort on this particular problem.

A second factor is the actual amount of any given critical cellular molecule or structure that is destroyed by radiation. For this and similar reasons we are now placing increasing emphasis upon investigations of how the radiosensitivity of individual cell components varies depending upon whether they are irradiated inside the cell or completely isolated from it. For instance, one sequence of phosphorylating reactions necessary for the

synthesis of DNA in cell nuclei is reported to be blocked by 100 roentgens. (L. Stocken, Radiation Research, Supplement 1, 53-72 (1959).) Experiments are now under way to separate these reactions from cellular structure and study their radiation response. However, past experience indicates this must be coupled with an extensive study of the interlocking reactions which account for this process within the cell. For example, carboxypeptidase - one of the intracellular enzymes capable of degrading other proteins - is a normal constituent of cells. Nevertheless, it is relatively inactive under normal conditions because it forms a complex with other cellular molecules. Without this latter knowledge it would be difficult to understand the initial increase in the carboxypeptidase activity measured in cells which had received increasing amounts of radiation. The apparent explanation is that the inhibiting complex is disrupted with lower doses than those required to inactivate the enzyme. (R. Feinstein and J. Ballin, Proc. Soc. Exptl. Biol. & Med. 83, 6-10 (1953).) Preliminary results (R. Feinstein) suggest that a comparable explanation may occur in the case of the enzyme deoxyribonuclease in certain cell fractions.

We are also continuing efforts to compare the radiation effects on nucleic acid exposed outside cells to that in chromosomes. The nature and number of the molecular changes produced by both external radiations and incorporated radioisotopes is being studied in viruses. Similar studies show that isolated nucleic acid fractions capable of entering a cell and changing it genetically ("transforming principle") require about 40 times as much radiation to produce an average of one observable genetic change per unit as do chromosomes.

The most fruitful studies will eventually deal with disturbances in interlocking and highly coupled reaction systems. However, because of a lack of fundamental knowledge in many areas we realize that most of our present projects must deal with effects on a particular kind of molecule, or at most a restricted set of reactions.

d) As a normal procedure some cells exclude certain atoms while selectively concentrating others. Only in this way can cells maintain their internal composition reasonably stable in the face of a constantly changing environment. This selectivity can be modified by numerous agents, including radiation.

Generally speaking the radioactive isotopes of concern in low levels of fallout must penetrate into cells and be retained there in order to damage the organism. Penetration is controlled by the permeability of the cell wall and membrane. Once inside, soluble materials can be selectively concentrated either by being bound to some cellular structure or by being incorporated into large molecules. The relative roles of the membrane permeability and internal concentrating processes in the case of individual elements for a variety of cell types are being examined by a number of our 19 projects in this field.

In addition, synthetic membranes, each capable of selectively passing ions from only one element are in the preliminary stages of development. These will be utilized for analytical tests and to simulate the selective properties of living cell membranes. Perhaps ultimately they will permit the development of techniques for removing fission products from water and food.

Studies are also under way to determine the pathways by which minute particles of insoluble material are taken up, transported andideposited in living organisms. This information is critical both with respect to fallout and plutonium processing.

e) The relative insensitiveness of biochemicals irradiated outside the cell has already been described. Further, most radiation is absorbed in the water which comprises about 90% of the cellular material. However, most critical biochemicals are not in "solution", but rather occur in ordered structures contained within the gel-like composition of the cell. Thus it was suggested in the fourth tentative explanation listed above that the mechanisms of "energy-interchange" within the ordered and semi-ordered cellular structures mediate the movement of energy from its point of initial absorption in such a manner that it is "funnelled" to critical sites.

It seems unlikely that these considerations alone could account for the thousand-fold disparity previously mentioned. However, recent data have demonstrated the potential importance of these mechanisms. When matter is irradiated,a variety of short-lived, highly reactive intermediates are formed before a terminal chemical reaction is reached. Some of these represent the formation of new chemical species; others appear to be only temporary molecular rearrangements. Under restricted irradiating and storage conditions, portions of the absorbed radiant energy can be trapped in one form of intermediate -- so-called "free radicals" -- for a day or longer. Evidence is now accumulating that there is a definite correlation between the expected radiation damage and the number of free-radicals which can be detected. Further, treatments which

reduce the number of free radicals also usually reduce the damage observed.

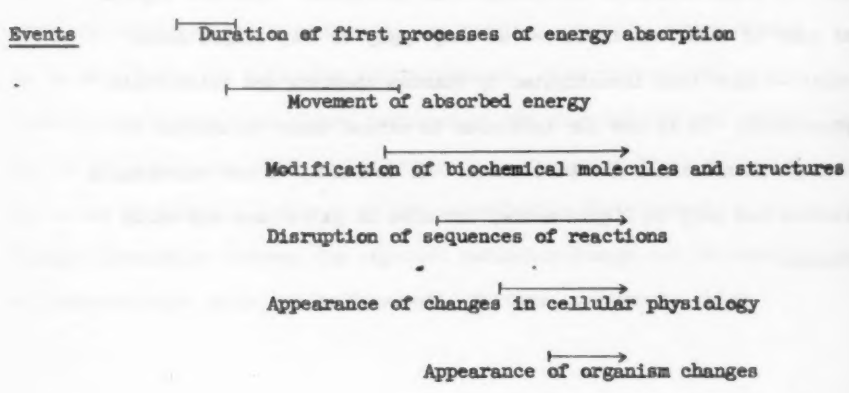
Similarly, free-radicals have been observed during photosynthesis and in enzyme reactions. Thus, considerations of energy-interchange mechanisms are not unique to radiobiology. Rather, they are part of the more general and extremely important problem of how relatively large-sized packets of energy can be maintained, relatively intact, in biological material for fairly long periods of time during which they may move or be transported over appreciable distances. Therefore, the questions of most immediate AEC interest will probably be solved only by an attack on this more general problem.

At present we provide $454,000 research support in this area. Eight of the 12 projects involve studies of the effects of ionizing radiations. Others deal with allied problems in photosynthesis and organic chemistry.

We are at present rapidly expanding our support of the following general topics: i) processes of radiation absorption; ii) stability criteria of excited states; iii) resonance transfer mechanisms; iv) electron transport in coupled systems; v) energy migration distances and vi) organization of microsomal-size particles. Numerous aspects of some of these six topics -- as they apply to very simple molecules -- have been investigated by quantum chemists and solid state physicists. It is now our intention to extend their techniques to biological molecules and structures. In addition, we are encouraging studies not only in liquid media, but also in gelatinous and solid states.

Summary: In the foregoing we have tried to indicate the importance of the research which the AEC supports at the molecular and cellular level. In particular we have shown how critical this information is to the understanding of the complex mechanisms leading to radiation damage. It should also be pointed out that the United Nations Scientific Committee on the Effects of Atomic Radiation has emphasized at their most recent meeting the importance of such studies for further progress in radiobiology. Our plans to place increasing emphasis and support in this area are also in accord with the UN Committee's feeling that the effects of studies at this level should have equal or greater promise than statistical experimentation involving large numbers of animals.

As a means of illustrating the kinds of mechanisms we feel are important in radiobiology, four potential explanations of how radiation damage is produced were listed. Quite possibly all four contribute. The chart below attempts to indicate where in the expected time sequence of radiobiological events the different mechanisms would play a role.


time in sec. 10^{-12} 10^{-9} 10^{-6} 10^{-3} 1 10^{3} 10^{6} . . . .
Events
Duration of first processes of energy absorption
Movement of absorbed energy
Modification of biochemical molecules and structures
Disruption of sequences of reactions
Appearance of changes in cellular physiology
Appearance of organism changes

It is normal that in any new area of science the factors investigated first are those of most immediate concern and for which measuring techniques are either available or can be readily developed. With increasing knowledge, new problems - invariably requiring more fundamental knowledge - become apparent. This has been the pattern of radiobiology in the AEC. Most of the past effort of the Division of Biology and Medicine has been concerned with either physical measurements of events which occur in the first 10^{-12} (one millionth of a millionth) seconds or else determinations of biological effects which appear quite some time after exposure. The problems which have evolved from these studies showed the need for knowledge of the processes occurring in the "in-between" time range. As a result, much of our present effort, as well as that planned, is directed at studies of the cellular events which occur in the first few minutes or hours. From the discussion presented in this appendix it should be apparent that we are now planning an increasing emphasis upon studies of those processes which occur in the even more restricted time region of 10^{-9} (one thousandth of a millionth) to 1 second after the absorption of energy. We feel the need for these studies is obvious. However, they will be costly and time-consuming. Unfortunately, most of the work done in this area has only dealt with very simple molecules. Thus, it will be necessary to develop a great deal of new methodology to deal with the complicated molecules and structures encountered in biological material.

We hope that the details presented here are adequate to give a comprehensive picture of how our present and planned research program in molecular biology contributes to the overall AEC efforts in radiobiology. Although we cannot promise to give immediate answers to many of the pressing problems, we feel our progress-some of it detailed above-is significant and encouraging.

APPENDIX G

CURRENT STATUS OF THE INTERNAL EMITTER PROGRAM

Prepared by John F. Bonner
Assistant Chief, Medical Research Branch
Division of Biology and Medicine
U. S. Atomic Energy Commission

The study of the long-term effects of internal emitters has been considerably accelerated during the past two years, although the impact of the expansion will not be felt in many programs for another year. This lag is caused by the time required to budget and appropriate funds and to design and construct additional large animal quarters, particularly for dogs.

The two main projects for evaluation of internal emitters using dogs are located at the Davis campus of the University of California and the University of Utah. Construction of the first stage of the animal facilities on the Davis campus was completed in 1958 and additional facilities, which will more than double the size of the animal quarters, have been authorized during the current fiscal year. At the University of Utah during 1957 and 1958 the initial small group of Sr-90 treated dogs was increased threefold to the same size as the older groups which had received the alpha emitters, plutonium, radium, mesothorium and radiothorium. In the older groups many of the animals are now 7 and 8 years of age.

Additional dog facilities are currently under construction at Argonne National Laboratory to house 264 dogs. These dogs will receive Sr-90 burdens very near and above the allowable levels as they are now recognized.

Renovation and new construction at the University of Rochester-AEP will provide space for an additional 200 dogs, 60 monkeys and 2,000 rats. This increase will allow for a modest expansion of a study of long-term effects of Sr-90 in monkeys started several years ago, but more important it will provide the isolated and sanitary environment so necessary for carrying out valid lifetime experiments.

The Los Alamos Scientific Laboratory is also expanding their animal housing to the extent of ten isolated mouse rooms plus space for a number of larger animals. These rooms will be used for long-term studies involving Sr-90 and other fission products.

The Commission is also providing support for construction and operation of a Radiation Biology Field Laboratory at Cornell University. This building will house large animals, for example, dairy cattle, with the special devices for studying the effects of radiation on domestic and laboratory animals, particularly in relation to evaluation of short- and long-term effects of fallout and environmental contamination. Special attention is to be given to the contamination of milk and the food chain.

Work at the Biology Division of the Hanford Operations has been increased to include the study of Sr-90 in several generations of swine.

As a conservative estimate, the number of animals involved in long-term experiments with Sr-90 at the end of 1959, will be at least double the number in existence in June 1957.

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The effort in this field represented by the off-site contract program with universities and medical schools has not increased, as it is difficult, if not impossible, to interest academic people in long-term studies, or to insure the necessary continuity of the program.

In addition to the basic long-term animal studies, it is imperative to collect as much information as possible concerning the burden of radioactive material in the living human population. The measurement and clinical evaluation of body burdens of radioactivity considerably above the average has been accelerated during the past several years.

At the beginning of 1957, only three whole body counters were in operation in Commission laboratories - two at Argonne National Laboratory and one at LASL. Although it has not been possible to measure the present body burdens of Sr-90 with these devices, much information of value in assessing the levels of internal gamma emitters in the population has been obtained. At LASL over 2,000 persons have been measured in the 4π liquid scintillation counter. This device will soon be replaced with a newer, more sensitive model, capable of giving more refined data. The ANL scientists were the first to show that Cs-137 is a measurable component of the human body. Later work at LASL has shown the half-time of Cs-137 in the human body to be about 120 days, in contrast with the 17 day figure obtained with rats and used for many years in the computation of the MPC for this radioisotope.

The increased ease and accuracy of determining gamma-emitting radioisotopes in the human body with the whole body counter has resulted in the construction and authorization of many more of these devices. By the end of 1959, between 15 and 20 whole body counters will be in operation, most of them located in AEC laboratories.

During the last two medical surveys of the Marshallese, whole body counting equipment has been transported to the Pacific, and definitive measurements made of the body burdens of fission products in this population. These studies will be continued and should prove to be an extremely valuable source of information in future years.

Another large sample of persons exposed to high levels of internal radioactive contamination is a group of former radium dial painters. The majority of these persons were exposed briefly over thirty years ago. They have now reached an age when the detrimental effects of radiation have had ample opportunity for expression. Even if the life-span of this group has not been appreciably shortened by radiation, we cannot expect it to remain indefinitely as a potential source of information. Only a few years ago the total number of known exposed workers in the United States was less than 200; now we believe the number in this country lies between 1,000 and 2,000.

Additional financial support has been given to a number of contractors to increase their effort in locating and examining these individuals. In

particular a contract has been made with the New Jersey State Department of Health to locate several hundred former workers known to have been employed in northern New Jersey.

It should be emphasized that this group of exposed persons is irreplaceable and that there is little possibility, short of all-out nuclear warfare, that a similar sample will ever again become available for study. Because all of the permissible levels of bone-seeking isotopes in man, including Sr-90, must necessarily be related to the observed effects of radium, it is obvious that we will continue to support and expand this program wherever possible. In fact, it may be desirable to increase the number of observations by extending assistance to investigators in foreign countries such as Switzerland, where radium dial painting has been at least as extensive as in the United States.

It should be noted that this description of the increased programs has not described the chemical, physiological and clinical studies that are aimed toward detecting any laterations in biological activity or function in experimental animals and man.

These studies vary with different programs and in different laboratories. In general, observations may be made of life span, incidence, type and age of occurrence of tumors and leukemias; composition of blood and other body fluids; skeletal growth and mineralization; fertility, and physical performance.

There is no new conclusive data concerning the concept of threshold versus non-threshold response for internal emitters, rather the evidence appears to show a non-linear type of response, with a maximum effect at higher doses.

Appendix H

ECOLOGICAL ASPECTS

By John N. Wolfe, Chief, Environmental
Sciences Branch, Division of Biology & Medicine
U.S. Atomic Energy Commission

Many of the most fundamental biological questions involving radioactive materials are ecological - in fact the final assessment of all biological experimentation is ecological. While ecology draws upon many major scientific disciplines for its raw materials, its unique contribution to biology is its study of biological systems at the community level, in relation to the total complex of climatic, biotic and edaphic factors that control them.

These kinds of investigations not only involve determination of patterns of range and distribution of biological assemblages such as forest, grassland, desert, and tundra, and less definitive communities of marine and freshwater systems. They include also biological processes such as food production, succession, migration, reproduction, ecesis; and such phenomena as population trends, periodicities, fluctuations; and persistence or elimination.

Such studies require multiple and repeated observation, areas in which to make these observations, and time in terms of decades. There is no substitute for time in ecological investigations, involving as they do, biological systems of land and/or seascape magnitude. No amount of laboratory analysis, dissection or experimentation, for example, will divulge the migratory route from Baffinland over Newfoundland, Pernambuco, Rio de Janeiro, Buenos Aires, to the pampas of Argentina of the golden

plover - a 9300 mile journey twice each year; or to cite species of more obvious economic importance, migration of salmon, from freshwater homes to the sea and back to their precise origins in a period of years.

These and similar processes are as important in characterizing populations as their composition and communal structure. And deviations from these patterns of behavior are the results of environmental and/or genetic change. In fact, environmental changes may be recognized first in biotic phenomena.

Through various technologies, and by his very presence, man has modified his environment wherever he has gone. Examples of major edaphic and biotic changes are myriad and spectacular, and climatic alterations, while less definitive, are certain. Throughout his history he has wrought such changes in his environment that left death or migration his only alternatives. Here again there are multiple and striking examples of this in every peopled biotic region on the planet. If environmental modifications occur beyond the tolerances (ecological amplitude, genetic conditioning) of populations, including man, migration or death is certain.

Radiation has become an intensified factor in the environment of man and the living things upon which he is dependent for food and shelter. The ecological effects of this increase are not known. Nor can they be determined by experiment alone, nor by considering only a single source of increased radiation, such as fallout. Determination of the total impact of this factor on man's biotic environment and the evolution of living organisms therein, is a continuing problem.

Long-time research programs in every major climatic, soils, and vegetation area are needed, planned not only to measure radiation, but to provide fundamental information about natural environments against which a realistic assessment of the long-term impact of radioactive contamination might be made.

To these ends, ecological laboratories, on and off AEC sites are needed. Here, not only could essential ecological studies be accomplished, but whatever monitoring seems necessary, could be carried on.

The major problems confronting man in atomic energy are ecological. Fallout, whatever its intensity, needs study as to its distribution and redistribution by wind, water, ice, food chains, biotic migration, and abscised plant parts. Disposal of radioactive by-products presents a continuing problem of an environmental nature, as do certain aspects of the Plowshare program.

Wherever man sets up major installations, knowledge of both the physical and biological environment is needed in planning and operation. These include geological, pedological and meteorological investigations, biological inventories, mapping, and inquiries into the dynamic aspects of communities (endemic and domesticated) which produce the needs for man and his culture.

Ecological researches that keep pace with both agricultural and engineering technologies are essential to assess biological costs of projects, to lend aid in the selection of reactor sites, to provide knowledge for biological reconstruction of damaged areas, to evaluate disposal sites by and large to provide a sound scientific basis for exploiting the environment.

Appendix I

THE STATUS OF BONE MARROW THERAPY

Prepared by H. D. Bruner, M. D., Chief
Medical Research Branch
Division of Biology and Medicine
U. S. Atomic Energy Commission

The emphasis on studies of bone marrow therapy has definitely shifted from the experimental animal to man. This is not to say that a considerable number of studies on experimental animals are not in progress. Experimental animals did prove the basic feasibility of marrow transplants but it has become more clear during the past two years that the immunologic characteristics of a given strain or species can be extrapolated only in a general way to another species.

It has been shown in animals that radiation and certain chemicals which suppress the bone marrow, lymphoid tissues and probably other elements of the reticulo-endothelial system, will also suppress the normal immunologic antagonism between species, strains and individuals to the point that tissues from another individual (and in some cases, species) are not immediately destroyed by the irradiated recipient.

The transplanted cells survive and multiply so as to become the progenitor lineage for those cells in the recipient. When this happens it can also be shown that tissues such as skin which formerly would not take on the recipient will now do so. Thus, it is possible to make a successful graft of rat skin on a mouse which is living because its bloodstream has been repopulated by transplanted rat bone marrow.

In many cases the transplant served to tide the recipient over the acute radiation effects whereupon the recipient's own blood-forming cells began to regrow with the result that both donor and recipient's cells circulated side by side for a while. In nearly all instances one finally beat out the other as an expression of the assertion of the immunologic type. In an animal with foreign circulating cells these foreign cells may be recognized as an antigen by the recipient's recovering immunogenic tissues, in which case the resulting antibodies, if produced in sufficient amount, would destroy all of the transplanted lineage of cells; such an animal could recover fully. At the other end of the scale the growing transplanted cells might recognize the normal components of the recipient's tissues as an antigen and thereupon produce antibodies which would suppress the cells of the recipient. In many cases this has happened, so frequently in fact, that the effect observed has come to be known as the "delayed reaction."

Establishment of the mechanism of the variations of this reaction has been one of the chief lines of development in this field. This basic problem of the "chimaera state" has been studied clinically, hematologically, immunologically and genetically with general agreement as to mechanisms and reactions. It has yet to be demonstrated in man although there are claims of successful homologous marrow transplants.

The importance of this phenomenon goes far beyond the problem of marrow transplantation since if it can be understood for marrow transplants (which

can be done because of convenience, ease of handling and perhaps other characteristics) then we will be in a position to try to make transplants of other organs and tissues.

Following the early mouse and rat work there was an effort to apply directly to man the principles and ideas which had evolved from such studies. The results were decidedly negative. Among the several most probable reasons for this failure were the necessity of using human subjects who still retained considerable antibody producing potential or whose marrow would fail to accept transplanted marrow for the same reasons that caused their own marrow to die out; also it is likely that an insufficient number of cells were transplanted at any one time and they were not too well matched.

The use of patients with leukemia who had received whole body radiation in an amount sufficient to suppress the marrow and the leukemic process was and is a step in the right direction. The failure of United States workers to obtain "takes" in the several types of blood diseases under study continued to be most discouraging - then the Yugoslav criticality accident occurred and five of the six victims received single massive marrow transplants when their French physicians felt there was nothing else left to do, 27 to 36 days after exposure. This was quite contrary to what would be inferred from animal experiments, namely to transplant about the third day post exposure and certainly no later than the seventh day. Apparently the transplants in the Yugoslavs "took" at least to a degree. Accordingly all the hematologists are incorporating into their own human experiments the

factors which the French physicians partly by design and partly of necessity combined in carrying out the transplants. The French did enough unconventional things to keep the physicians busy for several years trying to evaluate the components of procedure which would make for a reproducibly successful transplant.

A group in Boston, under Dr. Dameshek, feels that it has had a measure of success in transplanting marrow into cases of aplastic anemia and plans soon to publish these findings. The observations are such as to set off confirmatory experiments in every laboratory working in this field. At the very least we may expect progress since the very fact of trying to check out these claims will lead to new data, new ideas or new hunches. Thus the French and the Boston data have created the fertile situation which frequently leads to progress in clinical research.

It was noted in several reports of animal experiments that transplants of splenic cells were more likely to result in failure of take and death than was true of marrow transplants. Presumably this was a result of the presence in splenic transplants of cells which were more active immunologically and hence antagonistic to the transplantation situation. This led to the idea of using fetal cells for the transplant since the immune status of the fetus and newborn is negligible compared to that of the adult. It was early recognized that fetal cells might produce antibodies against the host-recipient less actively than adult cells. It was also presumed that fetal cells might be more active producers of blood cells by virtue of being closer to the state

of rapid cell formation. They were not employed, however, because of difficulties in procurement and because they failed to give noticeably better marrow regeneration in animals. At present because of lack of success with other approaches and a somewhat improved supply of fetal marrow, the use of human fetal marrow in human cases of marrow failure has been revived and will be pursued strongly for at least the next two years.

Because of the presumed success of the fresh direct marrow transplant in the Yugoslav cases, emphasis on methods of preserving marrow in the frozen state will decrease, but because of the need for a steady supply of marrow and for other reasons, a basic program on techniques of procuring and storing transplantable marrow must continue. Unfortunately, very little progress has resulted from efforts to produce marrow cells in cultures in vitro, but this is a very difficult procedure and should be regarded as a long range project.

Despite the notable advances in marrow transplants, we are unable to specify which cell (or cells) is responsible for the generation of the blood cell lineages when a "take" is secured.

Appendix J

STATUS OF ANTIRADIATION PROJECTS

AET (S, β-aminoethylisothiuronium·Br·HBr) remains the prototype of the really effective prophylactic agent. In its own right it will shift the dose-response curve to the right by a factor of about 2. Thus if the $LD_{50/30}$ dose for rats is about 650 rads, the $LD_{50/30}$ dose for properly prepared rats can be raised to about 1300 rads. This treatment then combined with adequate bone marrow therapy will raise the $LD_{50/30}$ dose to 1800 to 2000 rads. In any case a given dose of AET will provide just so much protection; any dose level can be "broken through" by a sufficiently large amount of radiation.

The upper end of this drug-radiation dose cannot be evaluated because the drug is in itself toxic. The toxicity shows a definite species predilection in that the mouse and rat tolerate the drug reasonably well, whereas the dog and man begin to show alarming cardiovascular or gastrointestinal signs depending on route of administration, at doses so low as to be essentially useless in practice. The work of the past two years, therefore, has centered around efforts to find a derivative or congener of AET which would exhibit a more favorable effective dose/toxicity ratio. The two compounds given most consideration thus far are the propyl (APT) congener and the methyl derivatives of AET and APT. At present they have not received adequate tests in large mammals.

Most of the work in this field has been done at ORNL by Dr. David Doherty and at the Air Force Radiation Laboratory at the University of Chicago under Dr. Kenneth DuBois. In addition, a few small groups such as those at the University of Rochester-AEP and at UCLA-AEP have continued to

work with similar compounds. The work in this field at the Walter Reed Medical Center (Dr. Jacobus) has been along the line of studying possible combinations of cysteine and MEA which might reinforce or supplement each other on the assumption that the lethal effect of radiation on a cell was the result of the sum of several items of cellular damage. Similar studies with AET and PAPP have been carried out at the University of Tennessee (Dr. Overman). The experimental results in dogs have shown some increase in protective ability by the combined action of the drugs, but not sufficient to justify application to human populations.

The reports from the Air Force Radiation Laboratory nearly always contain one or more compounds which appear to exert a prophylactic, and sometimes therapeutic action, but subsequently little is heard of them. In any event these reports would provide the basis for an extensive synthetic-pharmacologic screening program and this apparently is what the Walter Reed group is considering in putting their $1.5 million allotment to work. (The first meeting of the Advisory Committee on the Walter Reed program was held on April 30).

On the whole the chemotherapy and chemoprophylaxis programs seem to be about on dead center. Perhaps the injection of the above $1.5 million is the impetus required to explore new compounds and generate new concepts. Drugs are still being suggested such as the new oral anti-diabetic compound, tolbutamide, but in each case the data supporting the suggestion was quite insufficient. In fact, during the past year there has been more interest shown in the oxygen effect and the mechanism by which it might work. The

older protective agents such as estrogens, narcotics, PAPP and SH-compounds continue to be considered active. A number of papers have been written on the value of various antibiotic agents; sometimes one agent, group or sequence of agents is described as more effective in promoting recovery from lethal doses of radiation.

(Thereupon at 12:35 p.m., a recess was taken until 2 p.m., the same day.)

AFTERNOON SESSION

Representative HOLIFIELD. The committee will be in order.

The Special Subcommittee on Radiation will continue the hearings. We have before us Dr. Francis J. Weber, Chief, Division of Radiological Health, Public Health Service, and Dr. Price and Mr. Terrill. Will you please come forward, gentlemen? You may proceed with your statement.

STATEMENT OF FRANCIS J. WEBER,[1] M.D., CHIEF, DIVISION OF RADIOLOGICAL HEALTH, ACCOMPANIED BY DR. PRICE AND MR. TERRILL, PUBLIC HEALTH SERVICE, U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Dr. WEBER. Mr. Chairman and members of the committee, it is an honor and privilege to appear before this committee and at this time comment on developments in this field from the point of view of the Public Health Service. Sooner or later, any health-influencing factor present in the external or internal environment of the human becomes a matter for evaluation and management by public health authorities where community health is involved, and by the personal physician in the case of the individual or the family. Ionizing radiation is now recognized as such a factor. This has become true during the present century, owing to the gradual increase in all sources of man-produced ionizing radiation.

For reasons such as these, the Public Health Service, on July 1, 1958, activated within its organization a Division of Radiological Health. Some months earlier, the Surgeon General appointed a National Advisory Committee on Radiation to assist the Service in studying those phases of the problem to which the Service might give proper emphasis in its program. Among the matters which have been given some special thought during the past several months is that which now engages the attention of your special subcommittee.

Prior to this opening session, Dr. Dunham was kind enough to acquaint me with the main topics included in his presentation and

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Education: Bachelor of arts, University of Pennsylvania, 1932; doctor of medicine, University of Pennsylvania, 1936; master of public health, Johns Hopkins University, 1939; doctor of public health, Johns Hopkins University, 1951.
Medical specialty: Diplomate, American Board of Preventive Medicine and Public Health.
Present position: Chief, Division of Radiological Health, Public Health Service, Department of Health, Education, and Welfare.
Experience: Commissioned in Regular Corps, Public Health Service, July 1, 1938. First field assignment to epidemiological studies in poliomyelitis under National Institutes of Health, followed by other studies in venereal disease, tuberculosis, and mental health programs. Public health experience has consisted of a succession of assignments, including 2 years in local health work in Georgia; division director with Michigan Department of Public Health; consultant in New Orleans and San Francisco regional offices; regional medical director for Cleveland and Denver regional offices; Assistant Chief and, later, Chief, Division of Tuberculosis Control, U.S. Public Health Service. Present assignment began July 1, 1958.
Professional organizations: Fellow in following organizations: American Medical Association: epidemiology section, American Public Health Association; American College of Preventive Medicine; and American College of Chest Physicians. In addition, membership in American Trudeau Society, National Tuberculosis Association, American Psychiatric Association, American Association of Public Health Physicians, Baltimore-Washington Health Physics Association, and others.

the way he planned to discuss them. For this I am very grateful. In his general review of developments since the 1957 hearings, he has presented in a very able manner the principal aspects regarding that part of the radiation total contributed by fallout from weapons testing activities. As you have heard, the amount of whole body or gonadal exposure derived from this is quite small compared to that from all extant sources or, for that matter, compared to natural background alone. Therefore, a first requirement for analysis of the problem is the casting of it in proper perspective. Were it not for certain pecularities of radioactive fallout, this would be simpler to do. These peculiarities make the effort difficult, and account for the special concern which ordinarily would not be accorded the problem if quantitative differences were the only consideration.

The agents involved, in the form of radioisotopes, such as strontium 90, iodine 131, cesium 137, and others, differ markedly from other toxicologic agents with which physicians have had experience, both in their nature and the fact of their relatively recent arrival on the clinical and experimental scene. The need for a further evaluation of such agents, and of the conditions of their appearance was recognized during the proceedings of the 1957 hearings in the form of a number of unresolved questions bearing on them. Dr. Dunham has reviewed the progress made during the interim in continuing attempts to resolve them. Therefore, the remainder of my comments will be confined to those aspects of the work which I believe have special relevance to Public Health Service activities and which the intervening period since 1957 has provided the Service with opportunities to examine.

One of the recommendations emerging from the 1957 hearings was that vigorous sampling programs be conducted to learn more about the distribution of radioactive fallout, and at the same time intensify efforts to trace the pathways through which the agents involved gain entry into man. As you have heard, the sampling program has been intensified during this period. In this program, the Public Health Service has continued its cooperation with the Atomic Energy Commission in collaborative efforts which go back to the early years of the Commission's organization. The number of air-monitoring stations and the number of water-sampling points at which radioactivity is being measured has been increased. Reports on these activities are made regularly to the Atomic Energy Commission, official health agencies and others with an interest in the results. The list of these activities is as follows:

PHS radiation surveillance network (app. A, "tabulation of findings for August 8 to December 31, 1958"). (This publication is on file with the Joint Committee.)

Water quality basic data network (app. B, "Summary of Radioactivity in Selected Surface Waters, October 1957–February 1959" (national water quality network)).

National air sampling network (app. C, "Report on the Radioactivity of Air Particulates, 1953–58," national air sampling network).

In addition, since the 1957 hearings, milk has been selected for special study, in the belief that this easily obtainable uniform product can yield important information on the cycle of air-rainfall-soil-plant-animal-man. Ten stations are now in operation under Public Health

Service auspices, plus certain other stations including a few now getting underway in State health departments (Minnesota, New York, Indiana, and others).

Our radiological laboratory at Cincinnati has developed practical methods for detecting various radioisotopes appearing in such foods as milk. If I may, Mr. Chairman, I would like to submit for the record recent technical publications describing the method and results obtained with it.

Representative HOLIFIELD. It will be received.

(The material referred to (app. D and E) appears on pp. 186 and 197.)

Dr. WEBER. The experience with the milk analysis program has proved instructive. This program which began with five stations in 1957 has revealed a gradually rising trend in levels of radioactivity, although the maximum levels have remained below the national and international permissible amounts. This is construed to reflect the environmental situation, since the source of the radionuclides found is believed to originate in plants which have received the fallout deposits. Since one of the public health aims is better control of any and all environmental contaminants of possible significance to human health, it has been necessary in program planning to take this trend into account, which trend we are told can be expected to persist for some time. ("The Nature of Radioactive Fallout and Its Effects on Man," p. 1353, article by W. H. Langham and E. C. Anderson quoting Libby et al. (Joint Committee on Atomic Energy hearings, 1957)) (report of the United Nations Scientific Committee on the Effects of Atomic Radiation: General Assembly official records, 13th sess., supp. No. 17 (A/3838) New York, 1958). Dr. Dunham has given in his presentation details derived from the abundant studies on this matter, all of which present a background for the special discussion of this subject to come later. In the meantime, special environmental investigations have begun in a small way, in the areas where levels are highest and if the budgetary proposals now before Congress are accepted, this can be better developed during the coming fiscal year. Like any other epidemiological problem, there are a number of links in the chain of transmission which, if better understood in terms of precise relationships, should aid in developing corrective measures. Good public health practice dictates that this be done early rather than late. Dr. Straub, who appears later in this program, is able to describe this in more detail.

The sampling program described this morning is quite important because it allows us to check on the presumed degree of exposure, and from that plus what we have come to know as a result of the important research program already referred to, we can estimate the probable uptake in living things. In the final analysis, this is what we need to know. Therefore, both of these activities, environmental analysis and research, are essential program elements if we are to do this.

As Dr. Dunham has pointed out, the logistics needed for a full-scale environmental sampling effort, however, are very impressive, but the fact remains that this activity requires expansion if we are to get a more accurate estimate of the problem and better manage the numerous factors introducing variability into the overall pattern.

Considerable assistance for a larger scale effort, however, would be made available should State and local health departments become more involved in the programs. Steps have already been taken in this respect. A case in point is the recent Denver conference called by the Surgeon General with the State and Territorial health officers, and joined by health officials from the Atomic Energy Commission (Conference on Radiological Health, April 13–14, 1959, Denver, Colo.) (conference agenda available to the committee). (See p. 257.)

To make a point now concerning health problems in general an agency like the Public Health Service needs to know the influence of all factors, singly or in combination, upon the health status of the individual. Although true of all diseases, a knowledge of such factors is particularly necessary in the chronic impairments, where, incidentally, such knowledge is harder to come by than is the case in acute conditions. This is pertinent to the subject under discussion here, because we are dealing with the possible long-term effects of low-level radiation exposures which could lead to certain types of chronic impairments. Therefore, if we are to either exclude or include radiation from fallout as a possible factor influencing health status, that type of knowledge must first be obtained.

This approach is not different from the general epidemiological one employed to investigate other multifactorial health conditions. Dr. Walsh McDermott, for example, has referred to certain diseases like tuberculosis as "hyphenated" diseases, because of the importance of many other factors in producing that state, factors that determine susceptibility in the first place and the character and progress of the disease when it occurs. Therefore, in his general review, Dr. Dunham has properly stressed the point that a trustworthy interpretation of the effects of radiation due to fallout (or, for that matter, radiation from any source) necessitates a knowledge of many factors. If we can be certain of having a sufficiency of such knowledge, at least to a reasonable degree, we are better prepared to say if the levels being encountered are acceptable, or not acceptable, in terms of the risks accepted during the course of normal healthful living.

This matter of permissible levels was brought up in 1957, as it is here being brought up again. This is a very complex subject, which has lately become a lively issue. As public health authorities responsible for community health, and as individual physicians responsible for individuals and their families, this problem is constantly brought to us now. To be able to advise correctly, we need to know what is a permisisble level in view of the well-known fact that uncontrolled radiation, in certain dosages at least, is followed by certain health impairments. To consider only the subject of fallout and its contribution, we are proceeding on the assumption that the present amounts of radiation in the enviroment from that source, and to which the general public is exposed, is within the stated permissible limits. This is said to be so because the amount now present, plus those additions which might be expected in the future from the comparatively slow descent of fission products still remaining in the stratospheric reservoir is, and will remain a fraction of natural background, insofar as external whole body and gonadal exposure is concerned.

At the same time, when one considers recent recommendations of the International Commission on Radiological Protection and the National Committee on Radiation Protection and Measurements respecting single organ exposures, while it appears the concentrations of radioisotopes derived from fallout will remain a fraction of that permitted, the latter fraction may not be negligible.

Dr. Dunham, in his prepared testimony, has discussed the many difficulties in formulating precise standards. The only answer that each of us can give, I am sure, is that we continue to measure and measure, and the research now underway be expanded. The number of investigators who are both able and willing to lay that patient siege to the truth which is necessary to solve this problem is still too few. Therefore, any formulation of it that can be arrived at now is but a resting stage en route to that goal.

In seeking to explore further, however, the final implications of the fallout contribution, we must of necessity, as the 1957 hearings noted, look at the whole problem of radiation throughout its broad range from its manifestation in natural background to the newer forms artificially produced. This is particularly important in the establishment of standards to ionizing radiation exposure, either as a whole or in its various parts. Indeed, natural background shows certain variations as the 1957 hearings also revealed, and, of course, artificially produced radiation from all sources is on the increase. The question then becomes one of how to balance all of these exposures in order to determine what total exposure may be in certain standard situations.

Therefore, workers in the field have had to adopt the technique of "averaging out" the various exposure levels, both for whole body and single organs, after giving due weight to the probable significance of each of the individual factors concerned in exposure. The data available for these estimates are considerably less than we would like to have, although each year adds some more to the total available. Speaking of Public Health Service activities in the data-collection field, the Service, with the advice of the National Advisory Committee on Radiation, is attempting to map out the areas of research which will give more of the kinds of data needed. Since the 1957 hearings, the influence of X-rays is being given a very close study in such research projects as the joint Public Health Service-National Office of Vital Statistics investigation of prenatal X-rays, in addition to special projects made possible by National Institutes of Health grants. In addition, a total environmental survey is being attempted in the Cincinnati, Ohio, area as part of the center's program there. Other pertinent studies include the examination of natural radioactive supplies, a determination of radioactivity in the Animas River in cooperation with the health authorities of New Mexico, Colorado, and Utah, and a continuation of the uranium mines study, located on the Colorado Plateau, which has now entered its 12th year.

Since, in general, these studies are concerned with effects in the low-level range of radiation, their further development should be of assistance in elucidating the type of problem we are considering here. Therefore, we are now attempting to give emphasis to the epidemiological and clinical phases of such projects, to a degree that our heretofore limited capabilities did not permit. The recruitment

and training program of the Service, made possible by increased appropriations since 1957, is finally helping us overcome this lack. This is much needed because the clinical problem is made especially difficult by the fact that disease syndromes induced by radiation are often indistinguishable from those brought about by other causes.

Representative HOLIFIELD. Before you leave that point, will you give us an idea of how much you have in your appropriations for this type of work, and how many trainees you have?

Dr. WEBER. Yes, sir. This fiscal year we have approximately $634,000, which represents an increase of a little over $200,000 over fiscal 1956. In training we conduct two types of training activities. First, the short course type of training which consists of nine separate courses of 1 to 2 weeks or more duration, and then we have the long-term academic program aimed to develop program directors which requires a minimum of an academic year in an outside institution. There are approximately 15 in that program at the present time with plans to extend that in 1960.

Representative HOLIFIELD. Are these to be teachers?

Dr. WEBER. Not necessarily. Their principal function will be to help States and local communities get their own comprehensive programs underway. Some will go into teaching and research, or, at least, include that in their work.

Representative HOLIFIELD. When did you get your first appropriation?

Dr. WEBER. The first separate appropriation?

Representative HOLIFIELD. Yes.

Dr. WEBER. I have that in the record here, Mr. Holifield, if I may look it up. The budgets for rad-health and this preceded the time when it became a division, as a separate line item began in 1949, with the sum of $17,639. That has progressed, as I said, to $634,100 this year, and then in the appropriation now before Congress, which has been approved by the House——

Representative DURHAM. Prior to that you had no request for any appropriation from the Government?

Dr. WEBER. Yes, sir; there were requests in for line items to do rad-health.

Representative DURHAM. You did not treat it separately as an item for radiological work?

Dr. WEBER. Yes, they were separate items, both in the engineering program, which was part of the environmental sanitation category, and also in the special health services program which was oriented to the medical and epidemiological phases. Since 1949, there have been identifiable appropriation requests for radiological health and certain funds have been made available, although not all that was asked for.

Representative HOLIFIELD. What is your funded 1960 budget?

Dr. WEBER. In the 1960 budget the House has approved a total program of $1,439,100, which represents an increase of $805,000. This

does not include certain funds derived from the Atomic Energy Commission. This morning Dr. Dunham referred to certain of those joint projects.

Representative HOLIFIELD. Can you give us the figure on the contract allowances under AEC contracts with the Public Health Service?

Dr. WEBER. Yes, sir; I can for each year. Would you like that later for the record, or now?

Representative HOLIFIELD. I would like to have it for the record, but will you give it to us for 1958 and 1959, if you have it?

Dr. WEBER. The sum is approximately a little over $600,000 from the AEC, Department of Defense, and the Maritime Administration. I am afraid, Mr. Chairman, I do not have the exact figures here.

Representative HOLIFIELD. Will you furnish that for the record?

Dr. WEBER. Yes, sir.

(The information referred to follows:)

Division of Radiological Health—Source of reimbursements (fiscal years 1958–59)

Source	Fiscal year 1958	Fiscal year 1959
Department of Defense	$47,700	$31,102
Navy, Bureau of Ships	7,290	8,664
Army	0	5,465
Joint Task Force 7	39,304	16,973
Naval Research Laboratory	1,106	0
Atomic Energy Commission	483,432	621,702
Albuquerque Operations Office (off site)	275,612	246,679
Idaho Operations Office (NRTS)	0	27,500
Chicago Operations Office	18,356	1,644
Oak Ridge Operations Office	0	1,060
Division of Biology and Medicine:		
Bone studies	0	26,400
Radiation network	38,876	66,366
Atomic Bomb Casualty Commission	70,500	81,500
Division of Reactor Development:		
Maritime surveillance studies	5,088	30,553
Radiochemical studies	75,000	140,000
Department of Commerce: Maritime Administration	0	17,030
Total	531,132	669,834

Representative HOLIFIELD. It is in the neighborhood of $600,000?

Dr. WEBER. Yes, sir; a little in excess.

Representative VAN ZANDT. Doctor, you have referred several times to the center at Cincinnati. Can you give us a general picture of the number of employees there and separating them by professions, say, physicists from technicians, and the amount of money you are spending annually and what proportion of their time is occupied in this field of radiation?

Dr. WEBER. Yes, sir. I can submit that for the record.

(The material referred to follows:)

PUBLIC HEALTH SERVICE, DIVISION OF RADIOLOGICAL HEALTH

POSITIONS AND FUNDS ALLOCATED TO ACTIVITIES AT SANITARY ENGINEERING CENTER, CINCINNATI, OHIO

That portion of the Division of Radiological Health staff stationed at the Sanitary Engineering Center, Cincinnati, consists of the following:

Supported by Division of Radiological Health funds appropriated to the Public Health Service

Activity	Fiscal year 1959		Proposed fiscal year 1960	
	Positions	Funds	Positions	Funds
Research	17	$124,400	26	$186,000
Training	11	80,800	26	191,200
Total	28	215,200	52	377,200

Supported by Atomic Energy Commission funds

Activity	Fiscal year 1959		Proposed fiscal year 1960	
	Positions	Funds	Positions	Funds
Research	16	$154,500	22	$199,000

Type of position	Fiscal year 1959	Proposed fiscal year 1960
Professional [1]	31	52
Technicians and clerical	13	22
Total	44	74

[1] Physicists, chemists, etc.

Representative VAN ZANDT. Can you give us a general statement now?

Dr. WEBER. I would say that over one-third of our radiological health budget is devoted to activities carried out at the Cincinnati center. So if we consider our present budget of $634,000, very roughly the Cincinnati program will be one-third of that: The program there is confined in the main, to investigations of the environmental aspects, plus training activities of the short course type.

Representative VAN ZANDT. This recruitment and training program is carried on at Cincinnati?

Dr. WEBER. It is really carried on here at headquarters as far as central direction is concerned, but our actual on-site training, which is to say the formal didectic training and the laboratory experience is conducted at Cincinnati.

Representative PRICE. How is your study divided with regard to work in ionizing radiation as against the fallout problem?

Dr. WEBER. We attempt to cover the comprehensive field of radiation, of which fallout is only regarded as a part. Special attention naturally is given to problems that may be induced by fallout because a number of these specific isotopes to which I referred are a reflection

of weapons testing activities. Our milk program is an example, with its chief reason for being the fact that we have to look for specific radioisotopes in milk, although certain natural ones like K–40 are also looked for.

Representative PRICE. There are some people who may be exposed to three different sources of radiation. That is, the natural exposure, then to the fallout problem and also those who work in industrial plants where you use regular isotopes will be exposed to a third source. How do you work out this permissible level when you take into consideration those who are exposed to three sources as against those who are exposed only to the natural radiation and the fallout hazard?

Dr. WEBER. I think that question would be difficult for me to answer this afternoon in our limited time. The three factors that you mentioned, I am certain, will receive adequate emphasis at your forthcoming session. In other words, I believe you are visualizing here a hypothetical situation.

Representative PRICE. That is not hypothetical. There are thousands who are in that category.

Dr. WEBER. Yes, sir. We could assume in the case of a person occupationally exposed, that he is also exposed to any extent fallout activities, and he would be exposed possibly in terms of ingestion of certain radionuclides. These factors are taken together, as I understand it, in the setting and formulation of standards.

Representative PRICE. They are taken into account in fixing the maximum permissible level to those who are exposed to ionizing radiation.

Dr. WEBER. Yes, sir, as I understand it.

Representative PRICE. That is, those who are exposed to natural radiation and to the fallout.

Dr. WEBER. They are factors that are given due weight. On the specific questions that relate to any detail concerned in standard setting, I would not be in a position to answer, because as you know I have never participated in the work of any of the standard-setting committees. But we do have others. Mr. Terrill, on my left, who might be able to give you a better interpretation, has served on various standard-setting committees of the NCRP.

Representative PRICE. I imagine that will be developed as we go along.

Dr. WEBER. Yes, sir; I am sure it will.

Representative DURHAM. Doctor, I am not saying this in any critical fashion at all, but I don't recall when the Public Health was established as an agency of the Government. It has been quite a number of years ago. We have had programs of all kinds for body treatment from foot to head. Since this was only initiated by request for appropriations in 1947, why do you suppose that we did not move into the field of radiation earlier and try to assess and evaluate the hazards to public health when it has been pretty well known since around 1890? This is not in criticism, but I would just like to have your opinion as to why we didn't move in this field.

Dr. WEBER. Yes, sir; I will be glad to answer your question, Mr. Durham. My earlier reply, I think, was addressed to the specific question which had to do with funds that may have been sought in particular years. It is true that particular year I mentioned was the

first year in which line item funds, as such, were sought and could be identified. Actually the Service did study radioactivity, or at least certain practical applications, for many years prior to that. In the 1930's the Public Health Service played some part in the watch dial painter studies. Dr. Scheele, who was formerly Surgeon General, investigated X-ray work in hospitals when he was a medical officer in the National Cancer Institute. Somewhat over 10 years ago I was chief of the Tuberculosis Division, at which time I remember we began a nationwide program of community miniature film X-rays. At that time we did begin a monitoring program of X-ray machines in an attempt to train technicians in safety. I will say that prior to weapons testing the matter of radiation was not too migh in the public eye nor did it get too much attention. It reminded me somewhat of attempting to stage a play before a house of empty seats, and yet it was very difficult to arouse interest in the matter, except on the part of professionals in the field.

The American College of Radiology, for example, has been interested for many years in safety measures in the use of X-rays, in the use of radium, and other natural radioisotopes. So actually it has a long history.

Representative DURHAM. I know it has.

Representative HOLIFIELD. Will you proceed, Doctor, as we are running a little behind in the schedule.

Dr. WEBER. Yes, sir. I thought I might say a final word, which has to do with public informational matters, and this is my last point.

As all will agree, public interest in atomic energy activities is very high. At the moment, the health aspect seems to be the one receiving greatest attention. It is obvious that this interest must be met by a willingness to share our information with the interested public. This is not as easy as it might sound, and in saying this, I am not referring to the fact that national security sometimes requires certain information pertaining to important defense activities be withheld for a time. What is most difficult is to attempt to translate the knowledge we have into language that is easily understood.

As Dr. Dunham pointed out, our culture holds a number concept in a certain limited, albeit a practically useful way. Posted speed limits on the highway illustrate the point. A motorist understands quite readily what is permissible and what is not permissible, if he just reads the sign. Numbers employed in the radiation field, which in themselves may be fantastically large, or equally small, in describing the events they represent, call for a much more advanced number concept.

For example, it is not easy to explain that maximum permissible limits are established with total exposure over a lifetime in mind. That is to say, if for a certain dietary element, an 80 micromicrocurie limit of a radionuclide per liter or kilogram, as the case may be, is exceeded on a certain day, it does not necessarily mean that the safety limits have been exceeded for the individual involved. On the contrary, it would only be exceeded if his whole exposure from such ingested materials averaged out that way and was further maintained at an

excess. Likewise, to put other such complicated matters in the few words to which we are ordinarily limited is not easy.

This should not be cause for discouragement, however, since other revolutionary breakthroughs in knowledge, of which the discovery of the causative role of micro-organisms in producing disease constitutes an example, have also had to await the spread of the new knowledge until general understanding appeared. With the greater ease and rapidity of modern communications, the present task should not prove too difficult. Although it will take some time, the arrival at that goal should be hastened as the peacetime applications of atomic energy increase in tempo, marked as that effort will be by the consequent widening of the circle of understanding participants which these activities afford.

That is the end of my statement.

Representative HOLIFIELD. Thank you very much, Mr. Weber. If we can establish in these hearings that very important point which you brought out, that we are dealing in millionths of millionths of curies in many of these measures, and millionths of curies and thousandths of a roentgen, over to the people's minds, I think it will carry an understanding which is not carried at the present time by general statements, such as the doubling of the content of radiation in milk or in wheat or in something like that. This has a significance much greater than the actual measurements that are involved. If we can just get that concept over that you state here, these hearings will be a success in allaying a lot of people's apprehensions in regard to the numbers used.

Are there any questions of Dr. Weber?

Representative BATES. Just one question, Mr. Chairman.

Mr. Chairman, I am sorry I am late, and this point might have been covered. Doctor, I wonder if you can tell us about the coordination which you have with the AEC? How is that set up?

Dr. WEBER. The coordination is quite close. I think the fact that we now have joint projects in the amount of over $600,000 with AEC is a concrete illustration of the fact that we do coordinate our programs. We go further than that over the broad field. For example, during the last budget year, as you know, the executive department, just as you are, is quite concerned with the matter of whether our activities are sufficiently interrelated that we work together. So we have compared our budgets, line item by line item. They have seen ours. We have seen theirs. We reached a common agreement on our respective budgets. That was presented to the Budget Bureau. I take it from that that each of us was permitted to ask for suitable appropriations in each of our activities.

Representative BATES. That includes your operating expenses as well as your individual line items?

Dr. WEBER. Yes, sir.

Representative BATES. So the whole thing is coordinated.

Dr. WEBER. Yes, sir.

Representative BATES. As far as the Public Health Service is concerned, it is satisfied with its status quo?

Dr. WEBER. As far as our present program is concerned, and the elements contained in it, we think it is a well thought out program and a useful program.

Representative BATES. From the point of view of protecting the public, you believe it is satisfactory?

Dr. WEBER. I can't answer that question with regard to the status quo. In the first place I would need a much more detailed knowledge of the AEC's program and of our own in the usual considerations that govern government, shall we say, but from where I sit merely as a division director in a bureau, I view our program as a well coordinated one.

Representative BATES. That is what I am asking, your judgment.

Dr. WEBER. Yes, sir.

Representative BATES. Thank you very much, Mr. Chairman.

Representative HOLIFIELD. Are there any further questions? If not, we will accept the material which you have submitted for the record, Dr. Weber, and thank you very much, gentlemen, for your testimony.

Dr. WEBER. Thank you.

(The material submitted by Dr. Weber follows:) [1]

[1] Appendix A to Dr. Weber's statement, "Tabulation of Findings for August 8–December 31, 1958," is on file with the Joint Committee.

Appendix B

National Water Quality Control Network

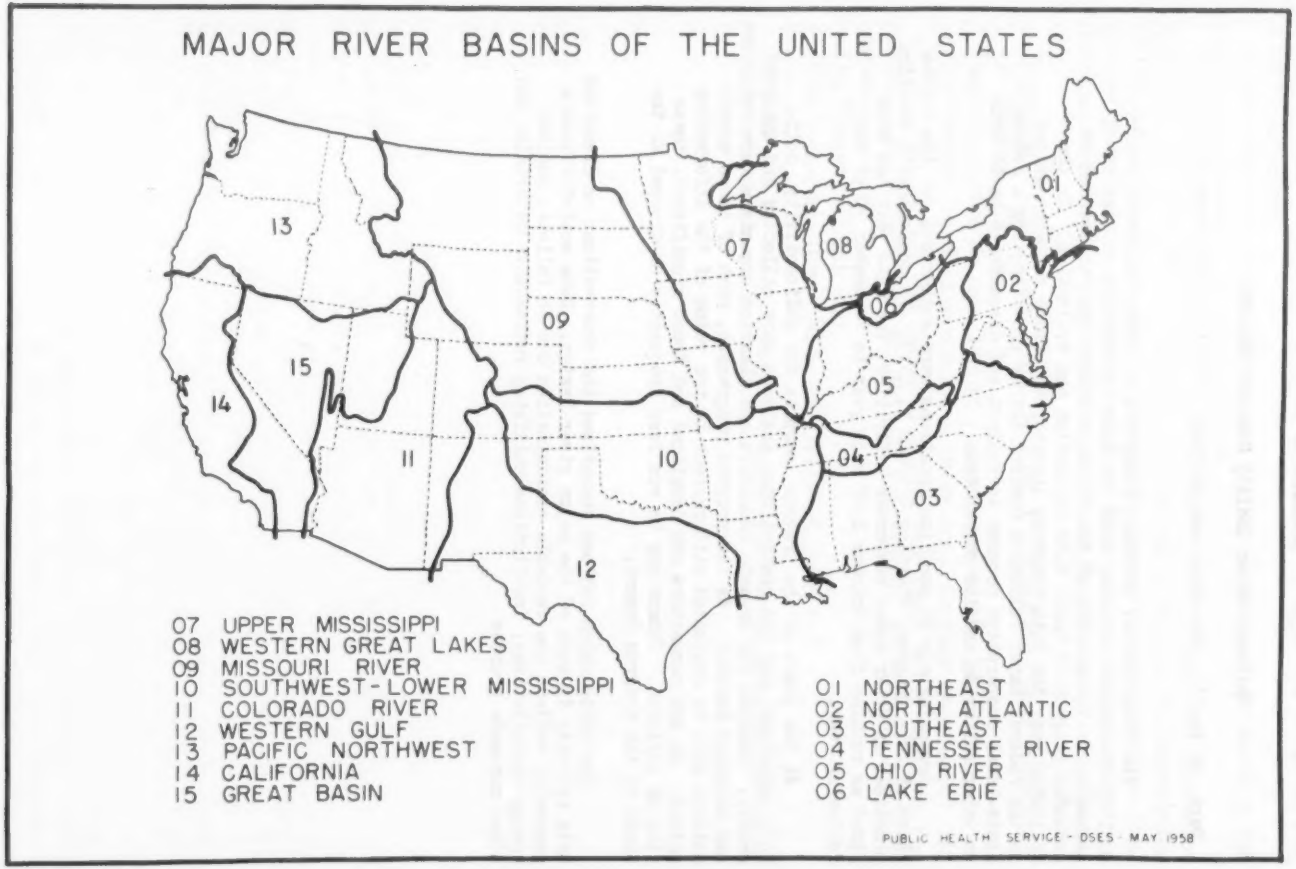
Dept. of Health, Education and Welfare - Public Health Service

The Presidential Advisory Committee on Water Resources Policy in 1955 recognized a strong need for more information on what is happening to the quality of the Nation's waters and recommended an expanded program of basic data collection and evaluation. In the following year the 84th Congress incorporated these recommendations in the Federal Water Pollution Control Act by providing for a Federal-State-local cooperative program to collect and disseminate basic data on water pollution and its prevention.

Approximately 50 sampling locations were authorized for the initial phase of this program, starting October 1, 1957. To conform with existing practices in other water resources activities, the data year has been fixed as running from October 1 of each year to September 30 of the following year.

At the start of the program, samples for radioactivity, coliform organisms, and the conventional analyses were collected and analyzed weekly. Samples for organic chemicals and plankton organisms were collected and examined monthly. As the program progresses, each of these examinations will be evaluated with respect to the value of the information gained. As new parameters are developed and found significant, these will be included. Others may be run less frequently or dropped as the needs of the program demand.

The table which follows summarizes the observations on dissolved beta activity in each of the major river basins. Beta activity levels generally reflect the variable contamination due to fallout, nuclear energy installations, institutions utilizing radioactive materials, and other man-made sources.



DISSOLVED BETA RADIOACTIVITY
In Surface Waters of the U.S.

DISSOLVED BETA RADIOACTIVITY
In Surface Waters of the U.S.
NATIONAL WATER QUALITY NETWORK

Median Readings in Micromicrocuries per Liter

MAJOR RIVER BASIN 1/	1957			1958												1959		
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Northeast	-	-	6	7	1	13	14	8	20	21	14	15	17	33	20	18	33	72
North Atlantic	-	10	10	4	6	7	11	16	17	28	27	18	31	30	14	28	23	28
Southeast	-	-	-	11	10	6	18	20	15	21	13	10	13	9	8	10	17	23
Tennessee River	-	-	-	-	-	4	30	22	17	46	52	37	18	29	20	17	27	34
Ohio River	-	16	8	8	4	6	15	19	23	51	36	23	26	32	21	21	24	24
Upper Mississippi	-	33	19	12	9	8	21	24	31	59	55	36	35	30	25	19	22	112
Western Great Lakes	-	7	5	6	2	1	3	7	8	14	18	14	13	8	11	8	6	13
Missouri River	-	27	22	23	11	16	26	33	37	66	42	35	35	25	26	24	20	62
Southwest-Lower Mississippi	-	17	11	13	9	8	19	24	39	63	55	47	25	26	29	20	32	66
Colorado River	-	22	11	16	11	9	26	22	25	30	36	19	30	33	22	33	35	48
Western Gulf	-	45	10	10	6	19	17	29	33	77	52	55	54	17	25	9	42	27
Pacific Northwest	-	482	468	311	471	192	183	141	94	193	189	122	129	28	28	93	44	39
U.S. Total	-	22	14	12	9	9	19	24	28	49	43	31	26	27	22	20	24	43

1/ No data available for
Lake Erie
California
Great Basin

DEPARTMENT HEALTH EDUCATION & WELFARE
Public Health Service
Division Water Pollution Control
Basic Data Branch

June 2, 1959

Appendix C

RADIOACTIVITY MEASUREMENTS NATIONAL AIR SAMPLING NETWORK OF THE PUBLIC HEALTH SERVICE

The Public Health Service has developed its National Air Sampling Network to secure basic data on the nature and extent of air pollution throughout the nation and to detect trends in levels of pollution with respect to time, location, population density, climate, and other factors associated with air quality. This network was began in 1953, to measure the protein particles in the air over 17 communities; in the three succeeding years the number of participating communities grew to 66. Meanwhile, growing interest in air pollution led to the passage of Public Law 159 of the 84th Congress in 1955, which placed a number of responsibilities in research and technical assistance in the Public Health Service.

The growth of national interest and the need for basic data, resulted in the network that exists today. The core of today's network consists of 117 sampling sites which are operated every year, of which 66 are large cities and 51 are non-urban sites. There is one non-urban, and at least one urban, site in each State. In addition to these every-year stations, 38 smaller cities have sites which are operated every other year, and 81 still smaller cities every third year. Thus, there are 236 sampling sites in all, of which about 160 are operating in any given year.

The National Air Sampling Network sites are manned by cooperating State and local agencies. Samples are collected approximately once each two weeks for a continuous period of 24 hours, under a predetermined schedule. Tests have shown that the results from this sampling schedule

are virtually as valid statistically as continuous sampling. At the end of each 24-hour sampling period, the local personnel mail the filter to the Sanitary Engineering Center of the Public Health Service for analysis. The analyses include the total quantity of suspended particulate matter, the organic matter soluble in benzene, and beta radioactivity. Selected samples are analyzed also for nitrates and sulfates, and for a number of metals. A comprehensive report on the first five years of operation of the network, including data tables, is contained in the publication, "Air Pollution Measurements of the National Air Sampling Network," Public Health Service Publication No. 637, which is for sale by the Superintendent of Documents. A map, showing the location of urban and non-urban sampling sites during the calendar year 1958, is shown below.

NATIONAL AIR SAMPLING NETWORK
APRIL 1959
NEW ENGLAND REGION
MID-ATLANTIC REGION
SOUTH-EAST REGION
MID-WEST REGION
GREAT PLAINS REGION
ROCKY MOUNTAIN REGION
PACIFIC COAST REGION
GULF SOUTH REGION
MAINE
NEW HAMPSHIRE
VERMONT
MASSACHUSETTS
RHODE ISLAND
CONNECTICUT
NEW YORK
PENNSYLVANIA
NEW JERSEY
DELAWARE
MARYLAND
WEST VIRGINIA
VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
FLORIDA
ALABAMA
MISSISSIPPI
TENNESSEE
KENTUCKY
OHIO
INDIANA
ILLINOIS
MICHIGAN
WISCONSIN
MINNESOTA
IOWA
MISSOURI
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MONTANA
WYOMING
COLORADO
NEW MEXICO
ARIZONA
UTAH
NEVADA
IDAHO
OREGON
WASHINGTON
ARKANSAS
LOUISIANA
PUERTO RICO
HAWAII
ALASKA
PACIFIC OCEAN

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, PUBLIC HEALTH SERVICE

R. A. TAFT SANITARY ENGINEERING CENTER, CINCINNATI, OHIO, AIR POLLUTION ENGINEERING RESEARCH—NATIONAL AIR SAMPLING NETWORK

Beta radioactivity by region and State, 1953 to 1958—Micromicrocuries per cubic meter

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
New England total:												
55 Number	8.0	6.0	2.0	—	8.0	1.0	2.0	3.0	2.0	2.0	4.0	5.0
Maximum	.8	1.4	.5	—	58.8	.7	.3	.5	.2	.2	.3	4.8
Average	.4	.5	.5	—	10.1	.7	.3	.3	.2	.1	.1	1.9
Minimum	.2	.1	.4	—	.4	.7	.2	.1	.1	0	0	.1
56 Number	6.0	4.0	4.0	4.0	5.0	4.0	5.0	4.0	4.0	3.0	—	1.0
Maximum	1.0	1.1	1.7	1.9	1.3	.9	1.5	.7	8.5	3.3	—	.7
Average	.5	.9	1.1	1.1	.7	.6	.7	.6	3.5	1.6	—	.7
Minimum	0	.6	.7	.2	.2	.3	.1	.5	.8	0	—	.7
57 Number	3.0	7.0	7.0	6.0	25.0	26.0	31.0	25.0	26.0	24.0	27.0	30.0
Maximum	1.2	1.9	3.8	8.5	8.1	25.0	49.0	32.0	29.1	18.8	3.7	4.0
Average	1.1	1.2	2.0	3.7	3.0	4.0	4.7	4.4	7.3	5.4	1.3	1.3
Minimum	1.0	.5	.9	1.5	.9	.9	.4	.9	1.3	1.1	.1	.1
58 Number	28.0	29.0	30.0	34.0	40.0	41.0	38.0	36.0	38.0	32.0	32.0	32.0
Maximum	5.7	3.4	21.0	16.0	11.0	8.5	10.0	5.0	5.1	33.0	29.0	86.0
Average	1.4	1.2	3.4	7.2	4.4	4.1	3.2	2.1	1.9	8.5	9.5	7.2
Minimum	.1	.1	.2	.7	1.2	.2	.3	.9	.1	.3	1.2	1.8
Connecticut total:												
55 Number	2.0	—	—	—	2.0	1.0	—	1.0	1.0	—	1.0	4.0
Maximum	.8	—	—	—	2.0	.7	—	.5	.1	—	.3	4.8
Average	.7	—	—	—	1.6	.7	—	.5	.1	—	.3	2.3
Minimum	.5	—	—	—	1.1	.7	—	.5	.1	—	.3	.4
56 Number	2.0	—	—	—	—	—	—	—	—	—	—	—
Maximum	1.0	—	—	—	—	—	—	—	—	—	—	—
Average	.5	—	—	—	—	—	—	—	—	—	—	—
Minimum	0	—	—	—	—	—	—	—	—	—	—	—
57 Number	3.0	4.0	2.0	5.0	7.0	4.0	9.0	5.0	6.0	6.0	6.0	7.0
Maximum	1.2	1.8	3.8	8.5	7.4	15.0	49.0	10.0	29.1	8.8	1.4	4.0
Average	1.1	1.2	2.9	4.1	3.5	5.9	11.9	3.0	11.0	3.9	.9	2.0
Minimum	1.0	.5	1.9	1.5	1.5	1.5	1.2	1.0	1.6	1.1	.1	1.2
58 Number	4.0	8.0	8.0	10.0	11.0	14.0	10.0	11.0	8.0	12.0	11.0	10.0
Maximum	2.6	1.9	3.7	10.0	7.7	8.5	5.0	3.6	2.7	22.0	20.6	6.5
Average	1.4	1.0	1.6	6.8	4.7	5.2	2.9	2.0	2.0	8.3	10.2	3.8
Minimum	.2	.1	.4	1.8	1.2	.9	1.1	1.1	1.3	.3	4.8	1.9
Maine total:												
57 Number	—	1.0	1.0	—	3.0	3.0	5.0	2.0	3.0	2.0	5.0	5.0
Maximum	—	1.2	1.4	—	2.7	3.2	2.4	1.2	2.2	3.8	3.7	1.5
Average	—	1.2	1.4	—	2.0	2.3	1.0	1.2	2.0	3.1	2.1	.9
Minimum	—	1.2	1.4	—	1.0	1.0	.4	1.1	1.7	2.4	.7	.2
58 Number	4.0	3.0	3.0	3.0	6.0	2.0	6.0	4.0	4.0	4.0	3.0	3.0
Maximum	1.7	3.4	21.0	11.0	6.7	2.4	6.4	2.3	1.8	13.3	29.0	9.3
Average	.8	2.2	7.6	8.0	4.3	1.9	3.2	1.7	1.1	5.8	15.3	7.3
Minimum	.2	.4	.6	5.7	2.0	1.3	.5	1.0	.2	.8	6.1	4.2
Massachusetts total:												
55 Number	—	—	—	—	6.0	—	2.0	2.0	1.0	2.0	3.0	1.0
Maximum	—	—	—	—	58.8	—	.3	.2	.2	.2	.1	.1
Average	—	—	—	—	13.0	—	.3	.2	.2	.1	.1	.1
Minimum	—	—	—	—	.4	—	.2	.1	.2	0	0	.1
56 Number	4.0	4.0	4.0	4.0	5.0	4.0	5.0	4.0	4.0	3.0	—	1.0
Maximum	.7	1.1	1.7	1.9	1.3	.9	1.5	.7	8.5	3.3	—	.7
Average	.5	.9	1.1	1.1	.7	.6	.7	.6	3.5	1.6	—	.7
Minimum	0	.6	.7	.2	.2	.3	.1	.5	.8	0	—	.7
57 Number	—	2.0	3.0	—	10.0	12.0	13.0	9.0	12.0	9.0	9.0	11.0
Maximum	—	1.9	2.8	—	8.1	25.0	10.2	32.0	21.4	10.4	1.9	1.9
Average	—	1.3	1.9	—	3.0	4.6	2.3	6.8	7.1	5.9	1.2	1.2
Minimum	—	.6	.9	—	.9	.9	.4	.9	1.3	1.2	.1	.1
58 Number	12.0	11.0	15.0	13.0	9.0	15.0	15.0	12.0	15.0	10.0	11.0	13.0
Maximum	5.7	1.9	19.0	14.0	11.0	7.2	10.0	5.0	5.1	33.0	15.4	86.0
Average	1.8	.9	3.4	6.3	5.3	3.5	3.7	2.7	2.0	11.1	8.4	10.9
Minimum	.1	.5	.2	.7	2.4	.2	.3	1.1	.1	.8	4.0	1.8
New Hampshire total:												
57 Number	—	—	—	—	2.0	1.0	—	2.0	1.0	2.0	1.0	2.0
Maximum	—	—	—	—	4.0	1.6	—	14.0	12.0	6.8	.6	.9
Average	—	—	—	—	3.2	1.6	—	7.7	12.0	4.3	.6	.9
Minimum	—	—	—	—	2.3	1.6	—	1.3	12.0	1.8	.6	.8
58 Number	2.0	2.0	1.0	1.0	2.0	1.0	1.0	2.0	3.0	2.0	—	3.0
Maximum	1.6	1.2	2.8	6.2	6.8	6.0	6.0	1.6	1.6	20.4	—	4.0
Average	1.5	.8	2.8	6.2	5.4	6.0	6.0	1.3	1.3	11.0	—	3.0
Minimum	1.4	.3	2.8	6.2	3.9	6.0	6.0	.9	.7	1.6	—	2.5

Beta radioactivity by region and State, 1953 to 1958—Micromicrocuries per cubic meter—Continued

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
New England total—Con.												
Rhode Island total:												
55 Number	6.0	6.0	2.0	—	—	—	—	—	—	—	—	—
Maximum	.6	1.4	.5	—	—	—	—	—	—	—	—	—
Average	.4	.5	.5	—	—	—	—	—	—	—	—	—
Minimum	.2	.1	.4	—	—	—	—	—	—	—	—	—
57 Number	—	—	1.0	1.0	1.0	3.0	2.0	3.0	1.0	2.0	1.0	3.0
Maximum	—	—	1.5	1.6	1.3	6.4	1.2	3.4	6.0	5.2	1.4	1.5
Average	—	—	1.5	1.6	1.3	3.8	1.1	2.4	6.0	3.3	1.4	1.4
Minimum	—	—	1.5	1.6	1.3	2.3	.9	1.0	6.0	1.4	1.4	1.3
58 Number	3.0	2.0	1.0	3.0	5.0	4.0	4.0	4.0	5.0	3.0	5.0	4.0
Maximum	1.4	1.1	8.8	16.0	6.3	4.7	2.3	2.5	3.2	13.3	15.8	17.2
Average	.9	.9	8.8	12.1	3.6	2.9	1.5	2.1	2.8	5.1	9.2	6.9
Minimum	.6	.8	8.8	4.4	1.4	.9	.4	1.9	2.1	.4	2.6	2.9
Vermont total:												
57 Number	—	—	—	—	2.0	3.0	2.0	4.0	4.0	3.0	5.0	2.0
Maximum	—	—	—	—	7.1	2.7	1.5	6.0	18.9	18.8	2.0	1.1
Average	—	—	—	—	4.0	2.2	1.1	2.3	6.7	11.0	1.3	.8
Minimum	—	—	—	—	.9	1.6	.7	1.0	1.9	4.0	.8	.5
58 Number	3.0	4.0	2.0	4.0	7.0	5.0	2.0	3.0	3.0	1.0	3.0	2.0
Maximum	1.1	2.2	.8	14.0	7.9	6.7	2.6	2.1	1.4	1.0	5.5	4.5
Average	1.0	1.5	.7	7.1	3.2	4.3	2.5	1.7	1.0	1.0	3.7	4.4
Minimum	1.0	1.0	.5	1.7	1.5	1.2	2.4	1.3	.4	1.0	1.2	4.3
Mid-Atlantic total:												
53 Number	—	—	—	—	—	—	—	—	1.0	3.0	8.0	6.0
Maximum	—	—	—	—	—	—	—	—	1.3	.8	.4	.1
Average	—	—	—	—	—	—	—	—	1.3	.6	.2	.1
Minimum	—	—	—	—	—	—	—	—	1.3	.3	.1	0
54 Number	3.0	—	2.0	—	1.0	6.0	7.0	9.0	17.0	15.0	26.0	34.0
Maximum	.1	—	.1	—	.3	.4	.6	.8	3.9	2.6	9.4	2.9
Average	.1	—	.1	—	.3	.2	.3	.3	1.7	1.4	2.0	1.3
Minimum	0	—	0	—	.3	.1	.2	.1	.1	.3	0	.1
55 Number	19.0	16.0	17.0	20.0	13.0	8.0	5.0	3.0	—	—	1.0	8.0
Maximum	1.5	1.6	3.5	91.2	54.4	1.5	1.0	.5	—	—	.5	1.3
Average	.6	.4	1.0	5.7	10.6	.8	.7	.3	—	—	.5	.8
Minimum	.1	.1	.1	.1	.4	.2	.3	.1	—	—	.5	.4
56 Number	4.0	3.0	—	—	—	—	—	—	—	—	—	—
Maximum	1.9	1.6	—	—	—	—	—	—	—	—	—	—
Average	1.4	1.2	—	—	—	—	—	—	—	—	—	—
Minimum	.3	.6	—	—	—	—	—	—	—	—	—	—
57 Number	—	—	1.0	—	37.0	34.0	34.0	33.0	29.0	33.0	31.0	24.0
Maximum	—	—	12.8	—	13.0	52.6	38.5	46.8	93.0	11.6	5.2	5.8
Average	—	—	12.8	—	3.6	4.9	5.3	4.4	12.7	4.7	1.5	1.7
Minimum	—	—	12.8	—	.2	.4	.4	.7	.5	.3	.5	.4
58 Number	25.0	26.0	34.0	34.0	33.0	36.0	33.0	36.0	18.0	34.0	29.0	25.0
Maximum	3.9	3.1	15.0	15.0	29.0	7.3	18.0	5.9	2.7	24.8	18.4	14.4
Average	1.6	1.3	2.4	7.0	6.1	3.9	4.4	2.5	1.5	6.5	8.1	6.1
Minimum	.1	.3	.1	.9	.7	.4	.8	.6	.1	.8	1.3	1.7
Delaware total:												
57 Number	—	—	1.0	—	3.0	3.0	2.0	3.0	—	2.0	5.0	1.0
Maximum	—	—	12.8	—	7.4	52.6	4.6	3.2	—	5.3	2.8	1.4
Average	—	—	12.8	—	4.1	20.0	2.8	2.9	—	5.1	1.9	1.4
Minimum	—	—	12.8	—	1.2	2.7	1.0	2.7	—	4.8	.8	1.4
58 Number	3.0	1.0	5.0	4.0	5.0	3.0	4.0	5.0	1.0	6.0	5.0	4.0
Maximum	3.5	1.9	15.0	12.0	9.9	6.2	5.3	5.9	1.9	20.0	18.4	8.3
Average	2.2	1.9	4.5	7.4	4.8	6.0	4.2	3.1	1.9	7.1	10.4	6.8
Minimum	.9	1.9	.8	3.4	.7	5.7	2.5	1.7	1.9	.8	6.0	4.2
New Jersey total:												
55 Number	10.0	2.0	—	—	1.0	—	—	—	—	—	—	—
Maximum	.7	.5	—	—	.4	—	—	—	—	—	—	—
Average	.4	.5	—	—	.4	—	—	—	—	—	—	—
Minimum	.1	.4	—	—	.4	—	—	—	—	—	—	—
57 Number	—	—	—	—	8.0	7.0	8.0	8.0	7.0	6.0	6.0	6.0
Maximum	—	—	—	—	6.6	23.0	38.5	3.1	74.0	11.6	5.2	5.8
Average	—	—	—	—	3.8	5.4	6.7	1.9	21.8	4.5	2.1	3.0
Minimum	—	—	—	—	1.8	1.0	.9	.7	2.6	1.7	.8	1.3
58 Number	7.0	7.0	11.0	9.0	8.0	10.0	11.0	8.0	7.0	10.0	10.0	9.0
Maximum	3.5	1.6	5.2	15.0	15.0	5.7	18.0	3.2	2.7	13.5	18.2	14.4
Average	1.3	1.2	1.5	7.9	6.8	3.6	5.6	1.9	1.6	6.5	8.8	7.1
Minimum	.1	.5	.1	5.1	2.8	.4	1.2	.6	.1	.8	3.2	1.7
New York total:												
53 Number	—	—	—	—	—	—	—	—	—	—	3.0	2.0
Maximum	—	—	—	—	—	—	—	—	—	—	.2	.1
Average	—	—	—	—	—	—	—	—	—	—	.2	.1
Minimum	—	—	—	—	—	—	—	—	—	—	.1	.1
54 Number	2.0	—	2.0	—	—	1.0	3.0	3.0	4.0	3.0	5.0	7.0
Maximum	.1	—	.1	—	—	.1	.3	.8	3.7	2.6	9.4	1.2
Average	.1	—	.1	—	—	.1	.3	.6	2.7	1.7	3.3	.9
Minimum	0	—	0	—	—	.1	.3	.5	.6	.9	.5	.1
55 Number	1.0	—	1.0	—	1.0	1.0	—	—	—	—	1.0	—
Maximum	.6	—	.1	—	.4	.2	—	—	—	—	.5	—
Average	.6	—	.1	—	.4	.2	—	—	—	—	.5	—
Minimum	.6	—	.1	—	.4	.2	—	—	—	—	.5	—

Beta radioactivity by region and State, 1953 to 1958—Micromicrocuries per cubic meter—Continued

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mid-Atlantic total—Con.												
New York—Cont.												
56 Number	2.0	2.0	—	—	—	—	—	—	—	—	—	—
Maximum	1.9	1.4	—	—	—	—	—	—	—	—	—	—
Average	1.1	1.0	—	—	—	—	—	—	—	—	—	—
Minimum	.3	.6	—	—	—	—	—	—	—	—	—	—
57 Number	—	—	—	—	14.0	10.0	14.0	10.0	12.0	13.0	12.0	10.0
Maximum	—	—	—	—	7.3	3.0	26.8	5.2	11.5	9.1	2.5	2.9
Average	—	—	—	—	3.2	1.9	4.9	2.3	4.0	5.3	1.1	1.3
Minimum	—	—	—	—	.2	.6	.4	.9	.5	.3	.5	.6
58 Number	4.0	7.0	5.0	8.0	10.0	10.0	6.0	4.0	9.0	17.0	9.0	11.0
Maximum	3.9	1.9	3.9	15.0	8.7	7.3	7.3	5.9	5.4	27.6	22.5	9.5
Average	2.1	1.0	1.9	5.9	4.3	3.1	4.3	2.6	2.1	10.6	11.5	6.5
Minimum	.1	.3	.8	1.7	1.3	1.3	2.7	1.0	.1	.6	2.5	2.9
Pennsylvania total:												
53 Number	—	—	—	—	—	—	—	—	1.0	3.0	5.0	4.0
Maximum	—	—	—	—	—	—	—	—	1.3	.8	.4	.1
Average	—	—	—	—	—	—	—	—	1.3	.6	.2	.1
Minimum	—	—	—	—	—	—	—	—	1.3	.3	.1	0
54 Number	1.0	—	—	—	1.0	5.0	4.0	6.0	13.0	12.0	21.0	27.0
Maximum	.1	—	—	—	.3	.4	.6	.3	3.9	2.5	3.7	2.9
Average	.1	—	—	—	.3	.2	.3	.2	1.4	1.3	1.7	1.5
Minimum	.1	—	—	—	.3	.1	.2	.1	.1	.3	—	.5
55 Number	8.0	14.0	16.0	20.0	11.0	7.0	5.0	3.0	—	—	—	8.0
Maximum	1.5	1.6	3.5	91.2	54.4	1.5	1.0	.5	—	—	—	1.3
Average	.8	.4	1.1	5.7	12.4	.9	.7	.3	—	—	—	.8
Minimum	.3	.1	.2	.1	1.2	.2	.3	.1	—	—	—	.4
56 Number	2.0	1.0	—	—	—	—	—	—	—	—	—	—
Maximum	1.7	1.6	—	—	—	—	—	—	—	—	—	—
Average	1.7	1.6	—	—	—	—	—	—	—	—	—	—
Minimum	1.6	1.6	—	—	—	—	—	—	—	—	—	—
57 Number	—	—	—	—	12.0	14.0	10.0	12.0	10.0	12.0	8.0	7.0
Maximum	—	—	—	—	13.0	18.8	22.3	46.8	93.0	6.5	3.0	3.1
Average	—	—	—	—	3.9	3.7	5.3	8.2	16.8	4.2	1.5	1.3
Minimum	—	—	—	—	1.3	.4	.8	.8	2.4	.5	.8	.4
58 Number	11.0	11.0	13.0	13.0	10.0	14.0	13.0	14.0	8.0	16.0	13.0	11.0
Maximum	2.7	3.1	7.9	13.0	29.0	6.6	6.7	5.2	2.6	24.8	16.6	10.9
Average	1.5	1.4	2.6	6.8	8.1	4.0	3.4	2.5	1.3	6.4	7.0	5.2
Minimum	.5	.6	.4	.9	2.2	1.4	.8	1.2	.1	.8	1.3	2.5
Mid-East total:												
53 Number	—	—	—	—	—	—	—	—	—	5.0	7.0	8.0
Maximum	—	—	—	—	—	—	—	—	—	.6	.5	.3
Average	—	—	—	—	—	—	—	—	—	.4	.3	.1
Minimum	—	—	—	—	—	—	—	—	—	.3	.2	0
54 Number	4.0	2.0	2.0	2.0	1.0	6.0	7.0	4.0	10.0	5.0	7.0	7.0
Maximum	.1	.1	.3	.2	.4	1.4	.9	.4	3.8	1.0	1.6	3.4
Average	.1	.1	.2	.2	.4	.5	.4	.3	1.3	.7	1.1	2.0
Minimum	0	.1	0	.1	.4	.1	0	.1	.3	.3	.6	1.0
55 Number	2.0	1.0	6.0	3.0	2.0	3.0	3.0	2.0	2.0	2.0	6.0	10.0
Maximum	.4	.3	4.6	2.0	3.5	1.0	1.4	.3	.3	.3	5.0	1.9
Average	.4	.3	2.3	1.3	3.3	.8	.9	.3	.3	.2	2.1	.9
Minimum	.4	.3	1.0	.8	3.0	.7	.5	.3	.3	.1	.2	.3
56 Number	5.0	4.0	4.0	4.0	4.0	4.0	2.0	5.0	2.0	3.0	2.0	—
Maximum	4.6	3.1	3.9	5.1	3.0	2.7	.9	9.3	4.0	6.0	1.8	—
Average	2.7	2.4	3.1	2.6	1.8	1.6	.8	3.5	3.6	4.7	1.8	—
Minimum	0	1.7	2.2	1.5	.7	.8	.6	1.8	3.1	2.5	1.8	—
57 Number	4.0	1.0	1.0	2.0	20.0	24.0	31.0	31.0	28.0	33.0	34.0	29.0
Maximum	1.8	.2	1.4	2.4	9.4	33.8	15.5	71.0	82.6	31.6	5.3	5.1
Average	1.4	.2	1.4	2.3	3.1	5.7	3.7	7.7	12.1	4.9	1.7	1.6
Minimum	.8	.2	1.4	2.2	.4	.6	.5	.4	.8	.6	.3	.4
58 Number	30.0	28.0	34.0	25.0	32.0	36.0	33.0	30.0	29.0	38.0	32.0	36.0
Maximum	6.1	3.1	12.2	21.0	16.0	7.5	13.0	8.6	5.0	34.5	19.2	16.4
Average	1.9	1.4	2.8	7.0	5.9	3.7	4.9	3.1	2.0	8.1	9.2	7.7
Minimum	.2	.1	.2	.6	.9	.2	.5	.5	.4	.5	1.8	2.5
District of Columbia total:												
53 Number	—	—	—	—	—	—	—	—	—	3.0	3.0	4.0
Maximum	—	—	—	—	—	—	—	—	—	.6	.4	.1
Average	—	—	—	—	—	—	—	—	—	.5	.3	.1
Minimum	—	—	—	—	—	—	—	—	—	.4	.3	.1
54 Number	3.0	2.0	2.0	—	—	—	—	—	—	—	—	—
Maximum	.1	.1	.3	—	—	—	—	—	—	—	—	—
Average	.1	.1	.2	—	—	—	—	—	—	—	—	—
Minimum	0	.1	0	—	—	—	—	—	—	—	—	—
55 Number	—	—	5.0	2.0	1.0	3.0	3.0	1.0	1.0	2.0	4.0	4.0
Maximum	—	—	4.6	1.1	3.0	1.0	1.4	.3	.3	.3	1.7	1.6
Average	—	—	2.5	1.0	3.0	.8	.9	.3	.3	.2	.6	1.0
Minimum	—	—	1.2	.8	3.0	.7	.5	.3	.3	.1	.2	.5

Beta radioactivity by region and State, 1953 to 1958—Micromicrocuries per cubic meter—Continued

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mid-East total—Cont.													
District of Columbia total—Continued													
56	Number	1.0	2.0	4.0	4.0	4.0	4.0	2.0	5.0	2.0	3.0	2.0	—
	Maximum	3.5	2.9	3.9	5.1	3.0	2.7	.9	9.3	4.0	6.0	1.8	—
	Average	3.5	2.3	3.1	2.6	1.8	1.6	.8	3.5	3.6	4.7	1.8	—
	Minimum	3.5	1.7	2.2	1.5	.7	.8	.6	1.8	3.1	2.5	1.8	—
57	Number	3.0	1.0	1.0	2.0	3.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0
	Maximum	1.8	.2	1.4	2.4	3.2	16.3	2.5	1.6	4.1	9.8	1.5	1.0
	Average	1.3	.2	1.4	2.3	2.0	8.9	2.1	1.1	3.5	7.3	1.4	1.0
	Minimum	.8	.2	1.4	2.2	1.2	1.5	1.7	.4	2.8	4.7	1.2	1.0
58	Number	2.0	2.0	3.0	1.0	1.0	3.0	1.0	2.0	3.0	1.0	2.0	3.0
	Maximum	3.3	1.1	10.0	6.1	4.3	4.1	2.2	3.1	2.2	17.6	16.4	7.6
	Average	2.1	.9	4.8	6.1	4.3	3.1	2.2	2.5	2.1	17.6	12.1	6.6
	Minimum	.9	.7	2.1	6.1	4.3	1.3	2.2	1.9	2.0	17.6	7.8	5.8
Kentucky total:													
54	Number	—	—	—	2.0	1.0	2.0	—	—	—	—	—	—
	Maximum	—	—	—	.2	.4	.8	—	—	—	—	—	—
	Average	—	—	—	.2	.4	.6	—	—	—	—	—	—
	Minimum	—	—	—	.1	.4	.3	—	—	—	—	—	—
55	Number	—	—	—	—	—	—	—	—	—	—	2.0	4.0
	Maximum	—	—	—	—	—	—	—	—	—	—	5.0	.7
	Average	—	—	—	—	—	—	—	—	—	—	5.0	.5
	Minimum	—	—	—	—	—	—	—	—	—	—	5.0	.3
56	Number	2.0	1.0	—	—	—	—	—	—	—	—	—	—
	Maximum	2.8	1.7	—	—	—	—	—	—	—	—	—	—
	Average	2.6	1.7	—	—	—	—	—	—	—	—	—	—
	Minimum	2.4	1.7	—	—	—	—	—	—	—	—	—	—
57	Number	—	—	—	—	1.0	1.0	1.0	2.0	2.0	2.0	—	2.0
	Maximum	—	—	—	—	6.4	3.1	6.5	4.1	72.8	31.6	—	5.1
	Average	—	—	—	—	6.4	3.1	6.5	2.9	42.8	20.1	—	3.5
	Minimum	—	—	—	—	6.4	3.1	6.5	1.6	12.7	8.5	—	1.8
58	Number	4.0	4.0	3.0	2.0	3.0	5.0	5.0	5.0	2.0	3.0	3.0	3.0
	Maximum	4.5	2.6	3.0	21.0	12.0	4.2	8.1	5.4	5.0	12.3	9.9	9.1
	Average	2.0	1.5	2.3	13.3	6.0	3.8	4.6	3.3	3.1	6.6	6.9	7.1
	Minimum	1.0	.2	1.6	5.5	2.6	3.0	2.2	2.1	1.1	2.4	3.7	5.9
Maryland total:													
57	Number	1.0	—	—	—	—	—	5.0	4.0	5.0	5.0	7.0	5.0
	Maximum	1.8	—	—	—	—	—	4.8	7.0	37.4	6.2	2.6	1.6
	Average	1.8	—	—	—	—	—	2.2	2.9	9.3	3.1	1.7	1.1
	Minimum	1.8	—	—	—	—	—	.5	.5	1.6	1.2	.8	.4
58	Number	4.0	4.0	5.0	3.0	5.0	5.0	4.0	3.0	4.0	4.0	6.0	3.0
	Maximum	3.5	1.3	7.5	4.6	9.0	7.5	5.1	3.9	2.5	15.0	15.4	7.7
	Average	1.8	.9	2.7	3.1	5.8	3.4	3.6	2.7	1.9	4.6	7.1	5.7
	Minimum	.9	.6	.2	.9	2.3	.2	1.5	1.2	1.1	.5	1.8	4.1
North Carolina total:													
57	Number	—	—	—	—	4.0	5.0	6.0	6.0	3.0	6.0	6.0	6.0
	Maximum	—	—	—	—	4.5	2.6	10.9	23.4	6.3	10.2	2.1	2.0
	Average	—	—	—	—	2.7	2.0	3.6	7.4	3.5	3.9	1.4	1.4
	Minimum	—	—	—	—	1.5	1.1	1.3	1.7	.8	1.0	.6	1.0
58	Number	8.0	8.0	9.0	10.0	7.0	9.0	7.0	5.0	6.0	12.0	6.0	10.0
	Maximum	6.1	2.7	12.2	15.0	12.0	7.0	12.0	8.6	3.3	34.5	14.8	16.4
	Average	2.2	1.5	4.3	7.1	7.0	3.1	6.4	3.8	2.4	11.9	10.4	9.9
	Minimum	.3	.1	.8	.6	4.3	1.1	1.7	.5	1.6	1.2	4.7	2.5
Puerto Rico, total:													
57	Number	—	—	—	—	—	2.0	2.0	2.0	2.0	3.0	2.0	1.0
	Maximum	—	—	—	—	—	1.2	2.3	5.0	5.8	2.9	.7	1.8
	Average	—	—	—	—	—	.9	2.3	3.0	4.3	1.5	.6	1.8
	Minimum	—	—	—	—	—	.6	2.2	.9	2.7	.6	.5	1.8
58	Number	—	—	3.0	—	3.0	1.0	3.0	4.0	5.0	4.0	5.0	4.0
	Maximum	—	—	2.5	—	2.7	1.8	1.7	6.9	1.6	2.8	10.1	8.5
	Average	—	—	2.0	—	1.7	1.8	1.2	3.2	1.0	1.9	5.4	4.7
	Minimum	—	—	1.1	—	.9	1.8	.5	1.7	.4	1.1	3.2	2.9
Virginia, total:													
57	Number	—	—	—	—	7.0	8.0	8.0	6.0	7.0	7.0	9.0	7.0
	Maximum	—	—	—	—	9.4	33.8	15.5	65.4	15.0	9.0	5.3	2.9
	Average	—	—	—	—	3.5	10.1	5.4	13.4	6.5	3.6	2.6	1.6
	Maximum	—	—	—	—	1.1	.6	2.0	.7	1.4	1.5	.3	.9
58	Number	6.0	5.0	6.0	6.0	7.0	8.0	6.0	6.0	6.0	7.0	7.0	6.0
	Maximum	3.4	2.0	4.2	11.0	9.5	7.0	13.0	6.7	4.0	17.4	17.0	11.2
	Average	2.2	1.5	1.3	7.0	6.7	4.7	6.8	3.4	2.3	5.6	9.4	9.3
	Minimum	.2	.9	.3	1.9	3.5	1.6	2.6	1.1	.9	.9	3.1	5.7
West Virginia, total:													
53	Number	—	—	—	—	—	—	—	—	—	2.0	4.0	4.0
	Maximum	—	—	—	—	—	—	—	—	—	.3	.5	.3
	Average	—	—	—	—	—	—	—	—	—	.3	.4	.2
	Minimum	—	—	—	—	—	—	—	—	—	.3	.2	—

Beta radioactivity by region and State, 1953 to 1958—Micromicrocuries per cubic meter—Continued

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mid-East total—Cont.												
West Virginia total—Continued												
54 Number	1.0	—	—	—	—	4.0	7.0	4.0	10.0	5.0	7.0	7.0
Maximum	0	—	—	—	—	1.4	.9	.4	3.8	1.0	1.6	3.4
Average	0	—	—	—	—	.5	.4	.3	1.3	.7	1.1	2.0
Minimum	0	—	—	—	—	.1	0	.1	.3	.3	.6	1.0
55 Number	2.0	1.0	1.0	1.0	1.0	—	—	1.0	1.0	—	—	2.0
Maximum	.4	.3	1.0	2.0	3.5	—	—	.3	.3	—	—	1.9
Average	.4	.3	1.0	2.0	3.5	—	—	.3	.3	—	—	1.5
Minimum	.4	.3	1.0	2.0	3.5	—	—	.3	.3	—	—	1.1
56 Number	2.0	1.0	—	—	—	—	—	—	—	—	—	—
Maximum	4.6	3.1	—	—	—	—	—	—	—	—	—	—
Average	2.3	3.1	—	—	—	—	—	—	—	—	—	—
Minimum	0	3.1	—	—	—	—	—	—	—	—	—	—
57 Number	—	—	—	—	5.0	6.0	7.0	8.0	7.0	8.0	8.0	6.0
Maximum	—	—	—	—	5.5	5.5	5.5	71.0	82.6	9.6	2.3	2.4
Average	—	—	—	—	2.9	3.7	3.2	11.0	19.4	4.7	1.3	1.7
Minimum	—	—	—	—	.4	2.5	1.6	1.3	.8	1.0	.3	1.1
58 Number	7.0	5.0	6.0	4.0	7.0	6.0	7.0	5.0	3.0	7.0	5.0	7.0
Maximum	2.5	3.1	2.9	11.7	16.0	5.3	6.8	2.7	3.2	18.9	19.2	9.2
Average	1.5	1.6	1.8	6.4	5.9	4.6	4.5	2.4	2.1	8.9	12.4	6.7
Minimum	.5	.9	1.0	1.1	1.8	3.6	2.2	1.9	1.0	2.4	6.4	5.0
Southeast total:												
53 Number	—	—	—	—	—	—	—	—	—	—	—	11.0
Maximum	—	—	—	—	—	—	—	—	—	—	—	.2
Average	—	—	—	—	—	—	—	—	—	—	—	.1
Minimum	—	—	—	—	—	—	—	—	—	—	—	0
54 Number	13.0	16.0	13.0	13.0	3.0	9.0	17.0	15.0	13.0	12.0	12.0	16.0
Maximum	.3	.1	2.8	1.5	1.2	.9	1.4	1.1	3.6	3.2	6.0	6.7
Average	.1	.1	.7	.6	.9	.6	.5	.5	.7	1.5	2.8	2.3
Minimum	0	0	.1	.1	.4	.3	.2	0	0	.1	1.0	.3
55 Number	24.0	17.0	15.0	13.0	8.0	11.0	11.0	12.0	2.0	2.0	3.0	5.0
Maximum	.8	10.4	6.9	53.3	61.3	3.9	.3	1.1	.3	.2	7.4	3.4
Average	.4	1.3	2.1	6.8	23.5	1.7	.2	.3	.2	.1	2.7	2.4
Minimum	.1	.3	.7	.4	1.2	.8	.1	0	.1	0	.3	1.0
56 Number	8.0	2.0	4.0	3.0	6.0	2.0	5.0	4.0	4.0	3.0	—	2.0
Maximum	6.4	4.9	2.4	3.8	2.4	1.6	13.7	3.4	6.1	2.9	—	.6
Average	3.8	4.1	2.0	2.4	1.2	1.0	3.8	2.0	2.4	1.8	—	.6
Minimum	.3	3.2	1.4	.9	.7	.4	.4	1.2	.9	1.1	—	.6
57 Number	4.0	3.0	3.0	6.0	27.0	28.0	32.0	34.0	33.0	43.0	35.0	31.0
Maximum	2.3	1.8	2.6	12.1	6.9	271.7	48.1	44.1	112.9	89.4	4.6	2.9
Average	1.1	.9	1.8	4.7	3.4	17.2	9.5	5.7	15.1	12.9	1.6	1.6
Minimum	.3	.4	.9	.3	.6	.4	1.7	.7	1.1	.4	.2	.7
58 Number	29.0	24.0	31.0	32.0	39.0	34.0	33.0	36.0	29.0	35.0	35.0	43.0
Maximum	7.1	4.2	22.0	12.0	16.0	5.9	21.0	6.8	5.3	39.0	30.8	20.0
Average	1.9	2.0	3.7	6.1	5.5	3.2	6.6	3.3	2.7	8.1	14.9	8.3
Minimum	.4	.9	.2	2.2	.4	.4	.7	.9	1.2	.2	2.6	1.6
Alabama total:												
57 Number	—	—	—	—	3.0	2.0	2.0	1.0	2.0	7.0	5.0	4.0
Maximum	—	—	—	—	6.1	4.3	23.4	5.9	14.6	12.6	1.7	2.2
Average	—	—	—	—	2.7	3.1	14.0	5.9	8.6	6.1	1.5	1.7
Minimum	—	—	—	—	.6	1.8	4.6	5.9	2.5	1.3	.8	1.2
58 Number	6.0	4.0	6.0	4.0	9.0	5.0	5.0	6.0	4.0	5.0	7.0	7.0
Maximum	1.9	2.8	12.0	10.0	11.0	5.9	18.0	6.8	5.3	10.0	20.3	11.4
Average	1.3	1.8	3.9	7.3	6.1	4.0	8.6	4.0	2.7	7.0	13.2	6.7
Minimum	.6	1.3	.9	4.4	1.7	1.4	2.4	1.9	1.2	2.6	2.6	1.6
Florida total:												
53 Number	—	—	—	—	—	—	—	—	—	—	—	7.0
Maximum	—	—	—	—	—	—	—	—	—	—	—	.2
Average	—	—	—	—	—	—	—	—	—	—	—	.1
Minimum	—	—	—	—	—	—	—	—	—	—	—	—
54 Number	7.0	6.0	4.0	7.0	1.0	1.0	8.0	7.0	7.0	5.0	7.0	8.0
Maximum	.3	.1	1.2	1.1	1.2	.8	.7	.6	.6	2.1	6.0	6.7
Average	.1	.1	.5	.6	1.2	.8	.4	.3	.3	1.3	3.5	2.2
Minimum	0	0	.1	.1	1.2	.8	.2	0	0	.8	2.3	.3
55 Number	6.0	7.0	8.0	4.0	2.0	4.0	3.0	6.0	1.0	2.0	3.0	1.0
Maximum	.6	1.1	4.3	3.1	61.3	1.7	.3	.6	.1	.2	7.4	2.5
Average	.3	.7	1.9	1.6	31.4	1.4	.2	.2	.1	.1	2.7	2.5
Minimum	.1	.5	.7	.4	1.4	.8	.1	0	.1	0	.3	2.5
56 Number	4.0	1.0	4.0	3.0	6.0	2.0	5.0	4.0	4.0	3.0	—	2.0
Maximum	6.4	3.2	2.4	3.8	2.4	1.6	13.7	3.4	6.1	2.9	—	.6
Average	4.8	3.2	2.0	2.4	1.2	1.0	3.8	2.0	2.4	1.8	—	.6
Minimum	1.7	3.2	1.4	.9	.7	.4	.4	1.2	.9	1.1	—	.6
57 Number	4.0	3.0	2.0	4.0	4.0	4.0	5.0	5.0	7.0	9.0	8.0	7.0
Maximum	2.3	1.8	2.6	5.8	4.2	47.6	9.7	43.1	34.0	65.8	4.6	2.4
Average	1.1	.9	2.3	2.0	2.7	13.7	4.7	11.4	10.0	18.2	2.3	1.6
Minimum	.3	.4	2.0	.3	1.8	1.2	2.0	.7	2.5	1.3	.8	.9
58 Number	6.0	6.0	5.0	8.0	7.0	7.0	4.0	6.0	7.0	7.0	5.0	11.0
Maximum	7.1	3.3	22.0	10.0	16.0	4.7	5.2	3.6	4.3	39.0	20.4	20.0
Average	3.1	2.9	8.0	6.2	4.2	2.8	4.0	2.8	2.7	10.8	10.3	8.9
Minimum	.9	2.7	3.8	4.4	.4	1.7	1.8	1.4	1.5	2.2	4.7	1.8

Beta radioactivity by region and State, 1953 to 1958—Micromicrocuries per cubic meter—Continued

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Southeast total—Cont.													
Georgia total:													
53	Number	—	—	—	—	—	—	—	—	—	—	—	4.0
	Maximum	—	—	—	—	—	—	—	—	—	—	—	.2
	Average	—	—	—	—	—	—	—	—	—	—	—	.1
	Minimum	—	—	—	—	—	—	—	—	—	—	—	0
54	Number	6.0	10.0	9.0	6.0	2.0	8.0	9.0	8.0	6.0	7.0	5.0	8.0
	Maximum	.1	.1	2.8	1.5	1.1	.9	1.4	1.1	3.6	3.2	2.4	5.5
	Average	.1	.1	.8	.5	.8	.6	.7	.7	1.2	1.5	1.7	2.5
	Minimum	0	0	.1	.2	.4	.3	.2	.2	.5	.1	1.0	.5
55	Number	6.0	8.0	7.0	5.0	5.0	4.0	4.0	4.0	—	—	—	2.0
	Maximum	.8	10.4	6.9	53.3	53.1	3.9	.3	1.1	—	—	—	3.4
	Average	.4	2.0	2.4	12.9	14.5	2.4	.2	.5	—	—	—	3.3
	Minimum	.1	.3	.9	1.6	1.2	.8	.1	.1	—	—	—	3.2
56	Number	2.0	1.0	—	—	—	—	—	—	—	—	—	—
	Maximum	5.1	4.9	—	—	—	—	—	—	—	—	—	—
	Average	2.7	4.9	—	—	—	—	—	—	—	—	—	—
	Minimum	.3	4.9	—	—	—	—	—	—	—	—	—	—
57	Number	—	—	—	2.0	6.0	6.0	6.0	6.0	5.0	9.0	5.0	5.0
	Maximum	—	—	—	12.1	6.9	11.5	23.8	9.2	19.6	9.7	3.6	2.9
	Average	—	—	—	10.0	3.3	4.8	7.2	3.3	10.9	5.3	1.5	1.8
	Minumum	—	—	—	7.9	1.1	.4	1.8	1.1	2.2	.4	.6	.7
58	Number	8.0	8.0	8.0	9.0	8.0	7.0	11.0	9.0	7.0	7.0	8.0	8.0
	Maximum	2.6	2.3	5.7	8.5	10.9	4.8	11.0	4.8	4.2	16.2	24.2	13.4
	Average	1.4	1.6	1.7	4.6	5.3	2.7	5.0	3.7	2.8	8.4	16.0	9.8
	Minimum	.4	.7	.6	2.2	1.5	.5	.7	2.8	1.5	2.5	9.2	3.6
Mississippi total:													
57	Number	—	—	—	—	2.0	1.0	3.0	7.0	4.0	8.0	5.0	6.0
	Maximum	—	—	—	—	1.2	8.8	10.2	44.1	112.9	89.4	1.6	2.6
	Average	—	—	—	—	1.1	8.8	5.4	8.8	29.4	29.5	1.2	1.8
	Minimum	—	—	—	—	1.0	8.8	1.7	1.6	1.1	2.0	.8	1.4
58	Number	4.0	4.0	4.0	5.0	5.0	3.0	3.0	4.0	3.0	6.0	2.0	4.0
	Maximum	3.5	2.9	4.7	9.2	7.5	5.7	6.0	3.7	3.3	12.4	20.9	9.3
	Average	2.6	1.9	2.2	5.3	4.9	2.8	5.7	3.2	2.8	6.1	17.7	5.8
	Minimum	2.1	1.3	.8	2.9	3.4	.4	5.1	2.1	2.2	.7	14.4	3.0
South Carolina total:													
57	Number	—	—	—	—	5.0	6.0	5.0	5.0	4.0	4.0	5.0	3.0
	Maximum	—	—	—	—	6.9	68.5	24.7	7.1	47.5	7.7	3.0	1.9
	Average	—	—	—	—	4.4	16.2	9.1	4.3	15.5	7.0	1.9	1.7
	Minimum	—	—	—	—	1.2	.9	2.3	1.6	3.1	6.2	.2	1.5
58	Number	3.0	1.0	2.0	1.0	3.0	2.0	2.0	3.0	1.0	2.0	2.0	4.0
	Maximum	1.9	4.2	8.7	12.0	6.3	5.5	21.0	5.2	2.1	12.6	17.9	15.0
	Average	1.4	4.2	4.5	12.0	4.1	4.4	12.7	3.5	2.1	6.4	12.9	10.4
	Minimum	1.2	4.2	.2	12.0	1.2	3.2	4.4	1.9	2.1	.2	7.8	4.1
Tennessee total:													
55	Number	12.0	2.0	—	4.0	1.0	3.0	4.0	2.0	1.0	—	—	2.0
	Maximum	.7	.5	—	11.6	52.7	1.5	.3	.2	.3	—	—	1.9
	Average	.4	.5	—	4.3	52.7	1.3	.2	.2	.3	—	—	1.5
	Minimum	.2	.5	—	1.1	52.7	1.1	.1	.1	.3	—	—	1.0
56	Number	2.0	—	—	—	—	—	—	—	—	—	—	—
	Maximum	4.1	—	—	—	—	—	—	—	—	—	—	—
	Average	2.9	—	—	—	—	—	—	—	—	—	—	—
	Minimum	1.7	—	—	—	—	—	—	—	—	—	—	—
57	Number	—	—	1.0	—	7.0	9.0	11.0	10.0	11.0	6.0	7.0	6.0
	Maximum	—	—	.9	—	6.1	271.7	48.1	5.5	73.1	9.0	2.1	1.4
	Average	—	—	.9	—	4.0	31.9	13.2	2.9	16.1	6.1	1.3	1.1
	Minimum	—	—	.9	—	1.1	.8	2.3	1.3	1.6	1.3	.2	.8
58	Number	6.0	6.0	9.0	9.0	7.0	10.0	8.0	8.0	7.0	8.0	11.0	9.0
	Maximum	2.9	1.6	8.5	11.0	14.0	5.5	15.0	4.9	3.9	24.1	30.8	13.1
	Average	1.5	1.3	3.4	6.8	7.0	3.2	7.8	2.9	2.8	8.1	17.3	7.8
	Minimum	.4	1.1	.9	2.3	3.7	1.3	1.2	.9	1.7	1.3	7.7	4.0
Midwest total:													
53	Number	—	—	—	—	—	—	—	—	—	1.0	25.0	14.0
	Maximum	—	—	—	—	—	—	—	—	—	.1	.6	.6
	Average	—	—	—	—	—	—	—	—	—	.1	.3	.1
	Minimum	—	—	—	—	—	—	—	—	—	.1	.1	0
54	Number	11.0	11.0	24.0	8.0	—	11.0	22.0	25.0	18.0	27.0	25.0	29.0
	Maximum	.9	.1	10.7	1.8	—	1.5	1.3	.8	5.8	2.6	4.9	4.9
	Average	.1	0	.8	.5	—	.6	.5	.4	1.2	1.5	1.5	1.4
	Minimum	0	0	0	.1	—	0	.1	.1	0	.4	0	0
55	Number	16.0	11.0	14.0	7.0	8.0	6.0	5.0	10.0	5.0	1.0	1.0	4.0
	Maximum	.8	2.9	38.3	9.9	6.4	1.5	1.0	.6	.5	.1	2.1	3.4
	Average	.3	1.1	6.8	3.0	2.9	1.0	.6	.4	.3	.1	2.1	3.1
	Minimum	.1	.2	.8	.3	.9	.3	.2	.1	.2	.1	2.1	2.7
56	Number	7.0	4.0	4.0	4.0	4.0	3.0	4.0	3.0	4.0	2.0	3.0	3.0
	Maximum	5.6	2.7	2.0	2.4	2.1	2.3	2.2	1.7	6.7	2.8	3.2	3.0
	Average	3.0	2.1	1.8	2.1	1.6	1.9	1.4	1.3	4.6	1.7	1.6	1.9
	Minimum	.9	1.2	1.6	1.8	1.2	1.7	.9	.9	2.1	.6	.7	1.

Beta radioactivity by region and State, 1953 to 1958—Micromicrocuries per cubic meter—Continued

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mid-West total—Cont.												
57 Number	2.0	2.0	2.0	5.0	48.0	43.0	47.0	45.0	40.0	39.0	49.0	48.0
Maximum	1.4	2.9	3.2	5.1	7.8	5.0	48.6	72.1	117.9	25.2	3.5	6.9
Average	1.0	1.9	2.4	3.5	3.3	2.5	6.9	6.9	13.9	5.6	1.5	1.6
Minimum	.5	.8	1.5	2.2	.3	.9	.8	.8	.4	.6	.3	.4
58 Number	45.0	43.0	43.0	42.0	51.0	40.0	48.0	46.0	52.0	45.0	41.0	41.0
Maximum	7.7	2.4	11.0	17.0	19.0	9.2	25.0	11.0	4.1	18.6	27.3	12.0
Average	1.8	1.2	2.6	8.3	6.9	4.8	4.6	3.3	1.9	8.8	9.3	6.1
Minimum	.4	.2	.4	.9	1.8	2.1	.2	.9	.4	.7	3.2	2.1
Illinois total:												
54 Number	—	—	—	—	—	9.0	12.0	10.0	13.0	4.0	11.0	13.0
Maximum	—	—	—	—	—	1.5	.9	.8	5.8	2.6	4.9	4.9
Average	—	—	—	—	—	.7	.4	.3	1.4	1.9	2.0	1.7
Minimum	—	—	—	—	—	0	.1	.1	0	1.5	.5	.7
55 Number	7.0	5.0	9.0	6.0	4.0	4.0	3.0	9.0	2.0	—	1.0	2.0
Maximum	.5	2.9	38.3	9.9	3.7	1.5	1.0	.6	.3	—	2.1	3.4
Average	.4	1.3	9.7	2.9	2.2	1.1	.9	.4	.3	—	2.1	3.1
Minimum	.2	.4	.8	.3	.9	.7	.7	.1	.2	—	2.1	2.7
56 Number	4.0	1.0	—	—	—	—	—	—	—	—	—	—
Maximum	5.6	2.7	—	—	—	—	—	—	—	—	—	—
Average	3.6	2.7	—	—	—	—	—	—	—	—	—	—
Minimum	.9	2.7	—	—	—	—	—	—	—	—	—	—
57 Number	—	—	—	1.0	3.0	3.0	5.0	3.0	4.0	3.0	3.0	4.0
Maximum	—	—	—	2.9	2.7	5.0	18.8	72.1	10.9	2.5	2.5	2.5
Average	—	—	—	2.9	2.4	3.2	7.4	25.1	5.9	2.0	1.7	1.9
Minimum	—	—	—	2.9	2.1	2.2	1.4	1.4	.4	1.0	1.2	.9
58 Number	8.0	9.0	7.0	6.0	9.0	6.0	12.0	8.0	8.0	7.0	8.0	8.0
Maximum	3.6	2.2	8.7	17.0	15.0	8.8	25.0	11.0	4.1	16.7	22.6	8.2
Average	1.6	1.6	3.9	10.4	8.5	5.4	6.9	4.3	2.1	8.7	8.5	6.3
Minimum	.8	.6	.9	3.3	5.0	3.0	.2	1.2	1.2	3.0	3.2	4.1
Indiana total:												
55 Number	—	—	—	—	2.0	—	—	—	—	—	—	—
Maximum	—	—	—	—	3.4	—	—	—	—	—	—	—
Average	—	—	—	—	2.8	—	—	—	—	—	—	—
Minimum	—	—	—	—	2.2	—	—	—	—	—	—	—
57 Number	—	—	—	2.0	18.0	10.0	17.0	12.0	9.0	20.0	12.0	12.0
Maximum	—	—	—	3.8	6.8	4.4	48.6	41.8	6.5	25.2	3.5	6.9
Average	—	—	—	3.6	3.3	2.5	8.6	6.9	3.8	7.0	1.4	2.1
Minimum	—	—	—	3.4	.5	1.6	.8	1.6	1.4	.7	.3	.6
58 Number	11.0	7.0	10.0	12.0	12.0	8.0	8.0	10.0	14.0	7.0	8.0	7.0
Maximum	4.8	1.9	5.6	15.0	10.0	8.9	5.9	5.0	3.0	21.0	12.7	8.4
Average	1.9	1.3	2.4	9.0	6.2	5.1	4.0	2.8	2.1	10.8	8.5	5.9
Minimum	1.1	.6	.4	.9	2.2	2.7	2.0	.9	.6	4.6	3.3	2.1
Michigan total:												
54 Number	—	3.0	—	—	—	1.0	2.0	—	1.0	—	—	—
Maximum	—	.1	—	—	—	1.0	.5	—	.4	—	—	—
Average	—	0	—	—	—	1.0	.4	—	.4	—	—	—
Minimum	—	0	—	—	—	1.0	.3	—	.4	—	—	—
57 Number	—	—	—	—	10.0	16.0	11.0	17.0	12.0	14.0	13.0	11.0
Maximum	—	—	—	—	6.0	4.0	25.0	36.2	70.6	10.0	2.8	2.2
Average	—	—	—	—	2.8	2.1	7.9	4.0	11.1	4.2	1.3	1.1
Minimum	—	—	—	—	1.1	.8	.9	.8	1.5	.6	.3	.5
58 Number	8.0	10.0	7.0	7.0	9.0	6.0	8.0	8.0	7.0	11.0	8.0	8.0
Maximum	2.4	1.6	2.9	15.0	11.0	6.9	8.4	3.5	2.5	16.4	12.6	10.6
Average	1.4	.8	1.0	6.3	6.4	4.5	4.2	2.1	1.7	6.8	7.3	5.6
Minimum	.4	.2	.4	1.5	1.9	2.9	1.4	.9	1.1	.7	2.7	3.3
Ohio total:												
53 Number	—	—	—	—	—	—	—	—	—	1.0	25.0	14.0
Maximum	—	—	—	—	—	—	—	—	—	.1	.6	.6
Average	—	—	—	—	—	—	—	—	—	.1	.3	.1
Minimum	—	—	—	—	—	—	—	—	—	.1	.1	0
54 Number	11.0	11.0	24.0	8.0	—	2.0	11.0	8.0	13.0	9.0	14.0	16.0
Maximum	.9	.1	10.7	1.8	—	.2	1.3	.6	3.3	2.0	2.7	2.8
Average	.1	0	.8	.5	—	.2	.7	.4	.9	1.3	1.2	1.2
Minimum	0	0	0	.1	—	.1	.2	.1	.3	.4	0	0
55 Number	9.0	6.0	5.0	1.0	2.0	2.0	2.0	1.0	3.0	1.0	—	2.0
Maximum	.5	2.1	3.1	3.3	6.4	1.1	.3	.2	.5	.1	—	3.4
Average	.2	.9	1.6	3.3	4.5	.7	.3	.2	.3	.1	—	3.1
Minimum	.1	.2	.8	3.3	2.5	.3	.2	.2	.2	.1	—	2.8
56 Number	3.0	3.0	4.0	4.0	4.0	3.0	4.0	3.0	4.0	2.0	3.0	3.0
Maximum	3.5	2.4	2.0	2.4	2.1	2.3	2.2	1.7	6.7	2.8	3.2	3.0
Average	2.3	1.9	1.8	2.1	1.6	1.9	1.4	1.3	4.6	1.7	1.6	1.9
Minimum	1.2	1.2	1.6	1.8	1.2	1.7	.9	.9	2.1	.6	.7	1.1
57 Number	2.0	2.0	2.0	2.0	15.0	12.0	12.0	11.0	13.0	17.0	18.0	17.0
Maximum	1.4	2.9	3.2	5.1	7.8	4.8	13.4	50.1	117.9	10.7	3.3	3.1
Average	1.0	1.9	2.4	3.7	4.1	2.9	4.3	7.1	26.2	5.0	1.7	1.5
Minimum	.5	.9	1.5	2.2	.3	1.6	1.4	1.1	1.5	2.4	.4	.4
58 Number	16.0	14.0	17.0	13.0	19.0	17.0	15.0	15.0	20.0	17.0	14.0	15.0
Maximum	7.7	2.4	11.0	13.0	19.0	8.2	9.3	8.3	3.2	18.6	27.3	12.0
Average	2.2	1.4	3.1	8.1	7.9	4.5	3.6	3.7	1.6	9.2	11.9	6.6
Minimum	.6	.2	.4	2.0	3.6	2.1	1.5	1.8	.4	2.4	3.7	3.2

Beta radioactivity by region and State, 1953 to 1958—Micromicrocuries per cubic meter—Continued

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mid-West total—Cont.												
Wisconsin total:												
57 Number	—	—	—	—	2.0	2.0	2.0	2.0	2.0	5.0	4.0	4.0
Maximum	—	—	—	—	2.5	2.1	2.9	2.8	21.5	23.1	1.1	2.7
Average	—	—	—	—	2.5	1.9	2.1	2.1	12.0	6.7	.9	1.3
Minimum	—	—	—	—	2.4	1.6	1.2	1.3	2.5	1.8	.3	.5
58 Number	3.0	5.0	2.0	4.0	5.0	4.0	5.0	5.0	3.0	4.0	4.0	3.0
Maximum	1.6	1.3	2.9	11.0	9.4	9.2	5.9	9.4	2.0	13.7	6.9	6.2
Average	1.1	.8	1.8	7.2	4.3	5.5	3.4	3.9	1.7	7.4	5.4	5.1
Minimum	.6	.5	.6	1.8	1.8	2.7	1.8	1.1	1.4	1.4	4.2	3.5
Great Plains total:												
53 Number	—	—	—	—	—	—	—	—	—	3.0	10.0	11.0
Maximum	—	—	—	—	—	—	—	—	—	.4	.7	.1
Average	—	—	—	—	—	—	—	—	—	.3	.4	.1
Minimum	—	—	—	—	—	—	—	—	—	.1	.2	0
54 Number	7.0	7.0	6.0	2.0	2.0	6.0	12.0	11.0	10.0	13.0	10.0	8.0
Maximum	.3	.5	1.3	.2	.6	1.1	1.1	.7	3.6	1.5	2.3	1.4
Average	.2	.1	.3	.2	.3	.7	.5	.5	1.1	.7	1.2	1.0
Minimum	0	0	0	.1	0	.4	0	.3	0	.1	.4	.5
55 Number	4.0	4.0	7.0	5.0	10.0	9.0	5.0	15.0	5.0	4.0	3.0	2.0
Maximum	.8	.5	1.0	3.6	6.1	7.0	.9	.6	.6	.4	.2	3.0
Average	.5	.3	.9	1.6	2.3	1.9	.5	.4	.3	.3	.2	2.5
Minimum	.2	.2	.6	.3	.2	.4	.2	.2	.1	.2	.1	2.0
56 Number	6.0	5.0	8.0	7.0	9.0	8.0	7.0	8.0	7.0	8.0	—	—
Maximum	4.9	1.6	3.5	3.3	4.3	3.5	2.9	3.6	11.7	9.3	—	—
Average	1.9	1.4	1.7	1.9	2.0	1.8	1.3	2.1	5.0	3.2	—	—
Minimum	.6	1.1	1.0	.8	1.0	.6	.4	.7	1.0	.8	—	—
57 Number	5.0	6.0	6.0	5.0	30.0	25.0	24.0	28.0	27.0	40.0	36.0	40.0
Maximum	7.4	4.5	3.0	6.0	12.7	70.5	324.0	131.6	73.8	73.0	2.9	56.0
Average	2.5	1.9	1.7	2.5	4.5	6.4	23.3	19.2	11.0	8.7	1.2	2.9
Minimum	.5	1.0	.5	.4	.2	1.0	1.5	.9	1.1	.3	.2	.4
58 Number	31.0	26.0	35.0	31.0	36.0	33.0	39.0	35.0	22.0	33.0	36.0	32.0
Maximum	4.4	3.6	18.0	22.0	17.0	7.7	13.0	17.5	6.6	33.7	68.2	16.4
Average	1.9	1.3	3.4	8.2	7.5	4.1	4.6	4.4	2.9	8.9	12.3	6.0
Minimum	.5	.5	.2	2.2	1.5	.9	.4	.7	.2	.2	.5	.8
Iowa total:												
57 Number	—	—	—	—	3.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0
Maximum	—	—	—	—	8.6	70.5	14.3	2.8	37.4	11.5	2.7	1.5
Average	—	—	—	—	4.8	36.3	8.1	2.5	19.7	7.8	2.3	1.2
Minimum	—	—	—	—	1.6	2.1	1.8	2.1	2.0	4.1	1.8	.8
58 Number	2.0	3.0	4.0	5.0	6.0	7.0	7.0	8.0	5.0	7.0	5.0	6.0
Maximum	1.1	2.0	2.9	9.8	10.0	5.4	4.8	4.1	6.5	15.9	13.7	6.3
Average	1.1	1.4	1.8	7.7	6.2	3.3	2.9	3.3	3.8	6.5	7.9	5.0
Minimum	1.0	1.1	1.1	4.7	1.5	1.9	1.2	2.7	.2	.2	3.7	2.4
Kansas total:												
55 Number	—	—	—	—	4.0	—	—	1.0	—	—	—	—
Maximum	—	—	—	—	6.1	—	—	.5	—	—	—	—
Average	—	—	—	—	3.3	—	—	.5	—	—	—	—
Minimum	—	—	—	—	2.0	—	—	.5	—	—	—	—
57 Number	—	1.0	1.0	—	5.0	5.0	5.0	4.0	2.0	4.0	3.0	4.0
Maximum	—	1.2	1.0	—	7.3	15.8	324.0	131.6	8.3	40.5	.9	3.6
Average	—	1.2	1.0	—	4.5	6.5	71.1	37.0	4.7	13.0	.7	2.0
Minimum	—	1.2	1.0	—	2.1	1.6	5.7	2.4	1.1	.5	.5	.8
58 Number	5.0	2.0	4.0	3.0	4.0	5.0	3.0	2.0	5.0	4.0	2.0	—
Maximum	4.4	1.8	10.0	9.9	13.0	5.9	7.6	8.4	4.5	33.7	68.2	—
Average	3.1	1.5	4.5	6.6	7.6	4.2	5.9	7.9	3.2	19.2	41.4	—
Minimum	2.1	1.1	.2	2.2	3.6	2.9	2.8	7.3	1.7	4.8	14.6	—
Minnesota total:												
53 Number	—	—	—	—	—	—	—	—	—	3.0	10.0	11.0
Maximum	—	—	—	—	—	—	—	—	—	.4	.7	.1
Average	—	—	—	—	—	—	—	—	—	.3	.4	.1
Minimum	—	—	—	—	—	—	—	—	—	.1	.2	0
54 Number	6.0	5.0	5.0	1.0	—	6.0	7.0	7.0	8.0	7.0	8.0	8.0
Maximum	.2	.1	1.3	.2	—	1.1	1.0	.6	3.6	1.5	2.3	1.4
Average	.1	.1	.3	.2	—	.7	.5	.4	1.0	.9	1.4	1.0
Minimum	.1	0	0	.2	—	.4	0	.3	0	.1	.6	.5
55 Number	4.0	4.0	5.0	2.0	4.0	4.0	3.0	12.0	4.0	2.0	3.0	2.0
Maximum	.8	.5	1.0	1.8	3.4	7.0	.9	.6	.6	.4	.2	3.0
Average	.5	.3	.9	1.5	1.7	2.7	.5	.4	.3	.3	.2	2.5
Minimum	.2	.2	.6	1.2	.2	.7	.2	.2	.1	.2	.1	2.0
56 Number	4.0	4.0	4.0	4.0	4.0	5.0	5.0	5.0	3.0	5.0	—	—
Maximum	1.8	1.6	1.7	2.0	2.6	3.5	1.4	3.4	9.2	5.3	—	—
Average	1.4	1.4	1.4	1.5	2.1	1.9	1.0	1.8	3.9	2.2	—	—
Minimum	.6	1.1	1.0	.8	1.7	.6	.4	.7	1.0	.8	—	—
57 Number	3.0	3.0	3.0	2.0	8.0	6.0	5.0	7.0	6.0	5.0	7.0	7.0
Maximum	1.1	1.7	3.0	1.3	12.7	2.2	46.8	25.8	15.2	11.8	2.0	1.8
Average	.9	1.2	2.0	1.2	4.6	1.6	12.9	8.0	5.5	7.7	1.1	1.2
Minimum	.5	1.0	1.4	1.0	1.3	1.0	1.5	.9	1.6	2.3	.2	.6
58 Number	6.0	5.0	7.0	6.0	6.0	4.0	9.0	5.0	6.0	6.0	9.0	5.0
Maximum	1.9	1.5	18.0	10.0	16.0	4.5	4.4	3.1	5.3	12.4	20.3	9.3
Average	1.1	1.0	5.5	8.0	6.7	3.4	2.6	2.5	1.8	3.8	7.7	5.5
Minimum	.5	.6	1.0	3.2	2.7	.9	.4	1.6	.2	.7	1.6	2.9

Beta radioactivity by region and State, 1953 to 1958—Micromicrocuries per cubic meter—Continued

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Great Plains total—Cont.												
Missouri total:												
54 Number	4.0	3.0	2.0	1.0	2.0	—	5.0	4.0	2.0	6.0	2.0	—
Maximum	.3	.5	.1	.1	.6	—	1.1	.7	2.0	1.0	.5	—
Average	.2	.2	.1	.1	.3	—	.7	.5	1.7	.6	.5	—
Minimum	—	.1	.1	.1	—	—	.4	.4	1.3	.1	.4	—
55 Number	—	—	2.0	3.0	2.0	5.0	2.0	2.0	1.0	2.0	—	—
Maximum	—	—	1.0	3.6	1.8	2.0	.8	.4	.2	.4	—	—
Average	—	—	.8	1.7	1.8	1.3	.5	.3	.2	.4	—	—
Minimum	—	—	.6	.3	1.7	.4	.2	.2	.2	.3	—	—
56 Number	2.0	1.0	4.0	3.0	5.0	3.0	2.0	3.0	4.0	3.0	—	—
Maximum	4.9	1.4	3.5	3.3	4.3	2.2	2.9	3.6	11.7	9.3	—	—
Average	3.1	1.4	2.0	2.6	1.9	1.6	1.9	2.7	5.9	4.8	—	—
Minimum	1.3	1.4	1.1	2.1	1.0	1.2	.8	.9	1.9	2.2	—	—
57 Number	2.0	2.0	2.0	3.0	6.0	4.0	4.0	6.0	8.0	8.0	9.0	8.0
Maximum	7.4	4.5	2.3	6.0	8.2	4.1	13.7	120.1	73.8	23.9	2.9	3.0
Average	4.8	3.1	1.4	3.5	3.2	3.0	9.0	35.4	15.8	9.6	1.4	1.7
Minimum	2.2	1.7	.5	.4	1.4	2.1	1.7	2.6	2.8	1.9	.8	1.1
58 Number	6.0	4.0	6.0	5.0	7.0	5.0	8.0	6.0	6.0	4.0	8.0	7.0
Maximum	3.6	1.9	5.5	14.0	10.0	6.9	13.0	8.6	6.3	18.0	31.8	16.4
Average	1.9	1.5	2.7	9.2	7.8	3.8	7.8	5.2	3.7	7.6	14.6	8.0
Minimum	.8	.8	.9	4.8	4.3	2.0	4.1	2.7	2.2	1.3	4.8	2.7
Nebraska total:												
57 Number	—	—	—	—	4.0	4.0	4.0	4.0	6.0	9.0	6.0	8.0
Maximum	—	—	—	—	2.0	14.3	11.0	27.8	22.3	12.3	2.6	56.0
Average	—	—	—	—	1.1	6.1	6.0	9.9	12.0	3.5	1.2	8.5
Minimum	—	—	—	—	.2	2.0	2.0	2.6	4.5	.3	.7	.7
58 Number	4.0	4.0	5.0	4.0	2.0	5.0	4.0	4.0	4.0	4.0	2.0	5.0
Maximum	3.9	2.7	5.3	7.5	8.1	7.7	12.0	7.4	3.3	15.2	4.1	10.8
Average	2.3	1.4	3.0	6.1	8.0	5.8	5.7	4.1	2.5	11.0	4.0	8.0
Minimum	.7	.5	1.3	4.9	7.9	3.2	2.6	1.7	1.9	1.5	3.9	5.0
North Dakota total:												
57 Number	—	—	—	—	2.0	2.0	2.0	3.0	1.0	7.0	6.0	6.0
Maximum	—	—	—	—	4.1	3.6	33.1	6.1	6.1	8.1	1.5	1.6
Average	—	—	—	—	4.1	2.8	26.7	3.9	6.1	3.3	.9	1.0
Minimum	—	—	—	—	4.1	1.9	20.3	1.7	6.1	.5	.5	.4
58 Number	5.0	4.0	5.0	6.0	5.0	4.0	4.0	5.0	4.0	5.0	3.0	5.0
Maximum	3.0	1.1	2.7	22.0	6.9	6.1	4.1	3.7	2.2	16.6	4.1	3.6
Average	1.9	.9	1.6	10.1	5.5	4.6	2.7	2.5	.9	9.4	2.3	1.6
Minimum	.8	.7	.7	5.2	3.6	1.8	.6	.7	.2	1.5	.5	.8
South Dakota total:												
57 Number	—	—	—	—	2.0	2.0	2.0	2.0	2.0	5.0	3.0	4.0
Maximum	—	—	—	—	3.2	1.3	7.4	54.9	8.9	73.0	1.7	2.7
Average	—	—	—	—	2.3	1.2	5.3	32.3	5.2	21.6	1.5	1.9
Minimum	—	—	—	—	1.4	1.0	3.1	9.7	1.5	1.0	1.4	1.4
58 Number	4.0	4.0	4.0	2.0	6.0	3.0	4.0	5.0	2.0	2.0	7.0	4.0
Maximum	1.9	3.6	7.1	11.0	17.0	5.8	5.9	17.5	6.6	26.5	37.4	15.0
Average	1.6	1.9	4.2	8.2	10.5	4.4	5.5	8.1	5.1	14.6	17.1	7.9
Minimum	1.3	1.0	.8	5.3	5.9	2.5	4.7	3.8	3.5	2.7	3.1	4.4
Gulf South total:												
53 Number	—	—	—	—	—	—	—	—	—	1.0	7.0	8.0
Maximum	—	—	—	—	—	—	—	—	—	.3	.4	.2
Average	—	—	—	—	—	—	—	—	—	.3	.3	.1
Minimum	—	—	—	—	—	—	—	—	—	.3	.1	0
54 Number	3.0	1.0	1.0	3.0	3.0	12.0	18.0	14.0	21.0	12.0	18.0	20.0
Maximum	.1	0	.4	2.1	3.9	3.0	.8	1.0	3.2	2.7	5.7	11.0
Average	.1	0	.4	1.2	1.9	1.2	.5	.4	1.0	.9	3.0	2.5
Minimum	0	0	.4	.4	.2	.1	.2	0	0	.1	.8	.4
55 Number	18.0	10.0	19.0	7.0	7.0	14.0	14.0	19.0	8.0	12.0	14.0	16.0
Maximum	2.3	15.2	10.0	5.1	14.5	3.9	.7	.7	.6	.4	4.8	4.1
Average	.5	4.1	2.3	2.5	9.1	1.6	.3	.2	.2	.2	1.2	2.3
Minimum	.2	.3	.6	1.8	1.4	.3	.1	.1	0	.1	0	.7
56 Number	11.0	10.0	8.0	6.0	9.0	4.0	4.0	4.0	3.0	5.0	2.0	—
Maximum	5.4	3.5	4.0	2.7	3.5	2.1	4.5	4.7	12.7	6.8	2.0	—
Average	2.8	2.1	2.3	1.5	1.3	1.3	2.5	2.7	7.5	2.8	1.7	—
Minimum	.3	1.3	.9	.6	.4	.5	.3	.8	3.0	1.4	1.4	—
57 Number	4.0	5.0	5.0	4.0	20.0	19.0	21.0	21.0	21.0	20.0	22.0	20.0
Maximum	1.5	2.4	5.7	3.0	7.4	99.9	27.7	71.3	193.1	53.5	3.8	3.2
Average	1.2	1.1	3.1	1.8	2.9	11.8	9.9	13.5	57.6	12.7	1.5	1.8
Minimum	1.0	.4	1.0	.3	.6	.8	1.5	1.4	1.3	1.4	.1	.8
58 Number	24.0	23.0	27.0	21.0	27.0	20.0	29.0	28.0	25.0	33.0	32.0	30.0
Maximum	3.6	4.5	12.5	15.0	13.0	9.7	85.0	7.7	5.0	33.5	39.3	16.8
Average	2.1	2.0	3.9	6.0	6.5	3.7	8.7	4.4	1.6	10.1	13.8	8.5
Minimum	.9	.8	.5	.7	1.6	.5	1.1	2.2	.1	.3	1.2	2.3
Arkansas total:												
57 Number	—	—	—	—	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0
Maximum	—	—	—	—	3.4	1.2	13.8	71.3	4.9	8.4	1.6	1.2
Average	—	—	—	—	2.4	1.1	8.6	26.4	4.4	5.9	1.5	1.2
Minimum	—	—	—	—	1.4	1.0	3.3	1.9	3.9	3.4	1.4	1.1
58 Number	2.0	2.0	3.0	2.0	2.0	1.0	3.0	4.0	4.0	3.0	4.0	5.0
Maximum	2.2	3.5	7.7	5.0	12.6	2.4	8.5	4.7	2.1	11.6	16.5	7.4
Average	1.8	2.6	5.1	2.9	9.8	2.4	4.5	3.9	1.1	6.7	10.5	6.4
Minimum	1.4	1.7	2.9	.7	6.9	2.4	1.1	3.2	.1	1.3	1.2	3.7

Beta radioactivity by region and State, 1953 to 1958—Micromicrocuries per cubic meter—Continued

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Gulf South total—Cont.													
Louisiana total:													
54	Number	—	—	—	—	—	4.0	6.0	4.0	10.0	2.0	6.0	10.0
	Maximum	—	—	—	—	—	.9	.8	.5	.9	.9	5.1	11.0
	Average	—	—	—	—	—	.7	.5	.4	.6	.9	2.9	3.3
	Minimum	—	—	—	—	—	.5	.3	.2	.2	.9	.8	.4
55	Number	8.0	4.0	8.0	4.0	4.0	8.0	8.0	6.0	2.0	8.0	8.0	12.0
	Maximum	.6	9.8	3.1	2.1	13.1	3.9	.4	.3	.1	.4	4.8	4.1
	Average	.5	5.2	1.4	2.0	7.3	1.8	.3	.2	.2	.3	1.5	2.2
	Minimum	.3	.5	.6	1.8	1.4	.8	.1	.1	.1	.2	.1	.7
56	Number	4.0	4.0	4.0	3.0	4.0	—	—	—	—	—	—	—
	Maximum	5.3	3.5	3.5	2.7	3.5	—	—	—	—	—	—	—
	Average	2.9	2.5	2.6	1.6	1.5	—	—	—	—	—	—	—
	Minimum	.5	1.3	1.0	.8	.6	—	—	—	—	—	—	—
57	Number	1.0	—	—	1.0	3.0	5.0	4.0	4.0	4.0	5.0	4.0	4.0
	Maximum	1.0	—	—	2.3	4.4	6.0	6.1	9.2	142.7	31.2	2.8	2.6
	Average	1.0	—	—	2.3	2.8	2.3	4.1	4.7	50.8	13.7	1.8	2.0
	Minimum	1.0	—	—	2.3	1.5	.9	2.6	2.0	7.2	6.2	.8	1.3
58	Number	3.0	1.0	2.0	2.0	2.0	3.0	2.0	2.0	1.0	4.0	4.0	4.0
	Maximum	2.7	3.2	12.5	8.7	7.8	4.1	6.5	4.2	1.7	26.4	15.7	12.0
	Average	2.1	3.2	7.9	8.3	6.5	2.9	5.1	4.0	1.7	9.9	13.6	8.6
	Minimum	1.5	3.2	3.3	7.8	5.1	.8	3.7	3.7	1.7	.3	9.8	2.3
Texas total:													
53	Number	—	—	—	—	—	—	—	—	—	1.0	7.0	8.0
	Maximum	—	—	—	—	—	—	—	—	—	.3	.4	.2
	Average	—	—	—	—	—	—	—	—	—	.3	.3	.1
	Minimum	—	—	—	—	—	—	—	—	—	.3	.1	0
54	Number	3.0	1.0	1.0	3.0	3.0	8.0	12.0	10.0	11.0	10.0	12.0	10.0
	Maximum	.1	0	.4	2.1	3.9	3.0	.8	1.0	3.2	2.7	5.7	3.9
	Average	.1	0	.4	1.2	1.9	1.4	.5	.4	1.3	.9	3.0	1.8
	Minimum	0	0	.4	.4	.2	.1	.2	0	0	.1	1.5	.5
55	Number	10.0	6.0	11.0	3.0	3.0	6.0	6.0	13.0	6.0	4.0	6.0	4.0
	Maximum	2.3	15.2	10.0	5.1	14.5	2.4	.7	.7	.6	.4	2.0	2.9
	Average	.6	3.5	3.0	3.1	11.5	1.3	.4	.3	.3	.2	.7	2.5
	Minimum	.2	.3	.6	1.9	7.5	.3	.2	.1	0	.1	0	2.1
56	Number	7.0	6.0	4.0	3.0	5.0	4.0	4.0	4.0	3.0	5.0	2.0	—
	Maximum	5.4	2.4	4.0	2.3	3.1	2.1	4.5	4.7	12.7	6.8	2.0	—
	Average	2.8	1.9	2.0	1.4	1.1	1.3	2.5	2.7	7.5	2.8	1.7	—
	Minimum	.3	1.3	.9	.6	.4	.5	.3	.8	3.0	1.4	1.4	—
57	Number	3.0	5.0	5.0	3.0	11.0	9.0	13.0	10.0	12.0	9.0	11.0	10.0
	Maximum	1.5	2.4	5.7	3.0	6.4	99.9	27.7	67.2	193.1	29.8	3.8	3.2
	Average	1.3	1.1	3.1	1.6	23.	16.7	11.8	15.0	77.6	11.2	1.4	1.9
	Minimum	1.1	.4	1.0	.3	.6	.8	1.5	1.4	1.3	1.4	.1	.8
58	Number	14.0	15.0	13.0	11.0	17.0	11.0	16.0	14.0	14.0	17.0	11.0	14.0
	Maximum	3.4	4.5	7.6	13.0	12.0	7.1	8.4	5.9	5.0	33.5	27.2	13.7
	Average	2.1	2.0	2.9	6.5	5.3	3.2	4.0	4.1	1.4	11.7	13.4	8.7
	Minimum	.9	.8	.9	1.7	1.6	.5	1.5	2.2	.3	1.3	2.3	3.9
New Mexico total:													
57	Number	—	—	—	—	2.0	2.0	2.0	1.0	2.0	2.0	2.0	2.0
	Maximum	—	—	—	—	7.0	57.5	15.0	1.8	53.9	14.8	2.1	1.9
	Average	—	—	—	—	5.1	29.8	11.0	1.8	31.7	8.1	1.5	1.6
	Minimum	—	—	—	—	3.1	2.0	7.0	1.8	9.5	1.4	.8	1.3
58	Number	2.0	1.0	3.0	2.0	2.0	2.0	4.0	4.0	4.0	6.0	4.0	3.0
	Maximum	3.6	2.0	12.0	15.0	13.0	9.7	85.0	7.7	4.9	17.6	12.7	16.8
	Average	3.6	2.0	5.3	9.2	11.5	8.4	34.0	6.0	2.3	9.1	9.5	10.1
	Minimum	3.5	2.0	1.9	3.4	9.9	7.1	14.0	3.5	1.0	1.8	6.8	4.3
Oklahoma total:													
57	Number	—	—	—	—	2.0	1.0	—	3.0	1.0	2.0	3.0	2.0
	Maximum	—	—	—	—	7.4	1.1	—	12.4	3.9	53.5	3.0	1.9
	Average	—	—	—	—	4.2	1.1	—	11.5	3.9	28.8	1.7	1.5
	Minimum	—	—	—	—	1.0	1.1	—	10.3	3.9	4.0	1.0	1.1
58	Number	3.0	4.0	6.0	4.0	4.0	3.0	4.0	4.0	2.0	3.0	9.0	5.0
	Maximum	2.3	1.8	11.0	4.1	9.3	4.1	13.0	6.2	2.9	12.9	39.3	13.1
	Average	1.6	1.6	3.4	3.2	7.3	3.7	7.4	5.0	2.4	6.6	18.0	8.8
	Minimum	1.1	1.0	.5	2.6	5.6	3.2	4.1	3.1	1.9	1.1	6.0	5.4
Rocky Mountain total:													
53	Number	—	—	—	—	—	—	—	—	—	—	—	2.0
	Maximum	—	—	—	—	—	—	—	—	—	—	—	0
	Average	—	—	—	—	—	—	—	—	—	—	—	0
	Minimum	—	—	—	—	—	—	—	—	—	—	—	0
54	Number	4.0	3.0	—	—	—	9.0	15.0	11.0	8.0	5.0	12.0	7.0
	Maximum	.7	.2	—	—	—	3.2	1.7	1.7	7.4	6.6	17.0	5.6
	Average	.3	.1	—	—	—	1.6	.9	1.1	2.6	3.4	6.1	2.9
	Minimum	.1	.1	—	—	—	.7	.3	.4	.5	.5	1.1	.7
55	Number	9.0	5.0	11.0	5.0	5.0	10.0	7.0	10.0	7.0	3.0	7.0	8.0
	Maximum	1.1	.8	2643.7	5.5	425.5	2.3	1.2	.7	.6	.2	5.4	7.7
	Average	.5	.5	408.2	3.1	86.8	1.5	.7	.3	.4	.1	1.1	3.5
	Minimum	.1	.1	.6	.8	1.1	.8	.3	.1	.2	0	.2	1.6

Beta radioactivity by region and State, 1953 to 1958—Micromicrocuries per cubic meter—Continued

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Rocky Mountain total—Continued													
56	Number	9.0	4.0	5.0	4.0	4.0	3.0	5.0	3.0	4.0	2.0	—	—
	Maximum	10.0	4.9	7.4	2.0	8.0	4.1	17.2	11.6	21.6	9.0	—	—
	Average	3.5	2.7	4.0	1.4	4.5	3.5	8.0	6.5	9.3	6.8	—	—
	Minimum	1.3	1.3	3.0	.1	1.7	2.7	.8	3.0	2.1	4.5	—	—
57	Number	3.0	4.0	3.0	3.0	16.0	13.0	13.0	10.0	11.0	12.0	10.0	14.0
	Maximum	4.9	4.6	2.5	4.6	14.0	21.4	156.0	5435.0	159.2	233.7	2.1	4.9
	Average	3.3	2.5	1.9	3.0	5.3	7.8	66.4	549.2	42.6	33.2	1.2	2.3
	Minimum	1.7	1.3	1.2	.8	.2	.7	3.3	1.2	2.6	.8	.2	.6
58	Number	17.0	18.0	19.0	15.0	19.0	17.0	21.0	18.0	19.0	17.0	19.0	21.0
	Maximum	4.9	2.9	16.0	29.0	24.0	16.0	57.0	8.8	6.4	51.0	38.3	19.5
	Average	2.2	1.8	4.9	9.8	8.8	6.3	13.8	5.3	3.6	10.4	13.7	10.1
	Minimum	.6	.9	.6	3.2	1.7	.6	1.5	.7	.9	2.1	2.3	1.8
Colorado total:													
54	Number	—	—	—	—	—	7.0	6.0	7.0	3.0	3.0	5.0	3.0
	Maximum	—	—	—	—	—	2.5	.9	1.7	6.1	6.6	6.3	5.6
	Average	—	—	—	—	—	1.5	.7	1.1	2.7	3.6	4.0	3.6
	Minimum	—	—	—	—	—	.8	.3	.4	1.0	1.1	1.1	1.1
55	Number	4.0	4.0	5.0	2.0	3.0	5.0	3.0	5.0	4.0	3.0	5.0	4.0
	Maximum	.9	.8	28.5	3.6	3.8	1.6	1.2	.5	.4	.2	1.2	3.4
	Average	.5	.4	9.6	2.2	2.2	1.4	.7	.3	.3	.1	.4	2.3
	Minimum	.1	.1	1.1	.8	1.1	1.2	.3	.1	.2	—	.2	1.6
56	Number	5.0	3.0	5.0	4.0	4.0	3.0	5.0	3.0	4.0	2.0	—	—
	Maximum	10.0	4.9	7.4	2.0	8.0	4.1	17.2	11.6	21.6	9.0	—	—
	Average	4.0	3.1	4.0	1.4	4.5	3.5	8.0	6.5	9.3	6.8	—	—
	Minimum	1.3	1.3	3.0	.1	1.7	2.7	.8	3.0	2.1	4.5	—	—
57	Number	2.0	2.0	1.0	1.0	2.0	4.0	4.0	—	4.0	4.0	4.0	6.0
	Maximum	3.3	1.8	2.1	4.6	5.7	21.4	106.3	—	159.2	63.1	1.5	3.2
	Average	2.5	1.6	2.1	4.6	3.4	18.0	85.3	—	86.6	32.1	.9	2.2
	Minimum	1.7	1.3	2.1	4.6	1.0	14.6	64.2	—	14.0	1.0	.2	1.6
58	Number	4.0	4.0	5.0	4.0	3.0	3.0	6.0	5.0	3.0	4.0	6.0	4.0
	Maximum	3.0	2.1	8.6	17.0	9.2	15.0	49.0	8.8	4.9	26.8	29.1	11.9
	Average	2.3	1.7	3.7	10.6	6.6	8.4	18.3	5.4	3.1	9.6	13.9	8.7
	Minimum	1.4	1.3	.6	8.3	3.1	4.6	5.5	3.5	1.2	2.5	4.3	4.6
Idaho total:													
57	Number	—	—	—	—	3.0	2.0	2.0	3.0	2.0	2.0	2.0	1.0
	Maximum	—	—	—	—	14.0	3.0	142.3	4.2	45.3	3.6	2.0	.6
	Average	—	—	—	—	7.6	2.4	77.8	3.0	29.5	2.6	1.7	.6
	Minimum	—	—	—	—	.7	1.7	13.3	2.1	13.6	1.5	1.4	.6
58	Number	3.0	4.0	5.0	3.0	4.0	5.0	4.0	4.0	5.0	2.0	3.0	5.0
	Maximum	2.3	2.9	59.8	25.0	10.0	16.0	10.0	7.8	6.4	5.1	38.3	19.5
	Average	1.4	2.1	16.3	11.5	5.6	8.2	5.2	4.6	4.1	3.7	22.8	11.0
	Minimum	.9	1.4	2.3	3.6	1.7	2.1	1.9	.7	1.6	2.3	9.9	1.8
Montana total:													
57	Number	—	—	—	—	3.0	2.0	2.0	2.0	2.0	3.0	1.0	3.0
	Maximum	—	—	—	—	8.9	3.3	24.1	3.7	8.2	3.0	.8	2.7
	Average	—	—	—	—	5.8	2.0	13.7	2.5	5.4	1.7	.8	1.9
	Minimum	—	—	—	—	2.8	.7	3.3	1.2	2.6	.8	.8	1.2
58	Number	4.0	4.0	6.0	4.0	4.0	4.0	4.0	4.0	5.0	3.0	3.0	5.0
	Maximum	2.0	2.6	16.0	29.0	9.4	5.8	6.1	7.5	5.5	6.0	10.6	16.2
	Average	1.5	1.6	6.7	11.8	4.9	2.6	3.4	4.9	2.9	4.1	7.9	9.4
	Minimum	1.3	.9	1.2	3.2	2.1	.6	1.5	3.8	.9	3.1	3.3	3.5
Utah total:													
53	Number	—	—	—	—	—	—	—	—	—	—	—	2.0
	Maximum	—	—	—	—	—	—	—	—	—	—	—	0
	Average	—	—	—	—	—	—	—	—	—	—	—	0
	Minimum	—	—	—	—	—	—	—	—	—	—	—	0
54	Number	4.0	3.0	—	—	—	2.0	9.0	4.0	5.0	2.0	7.0	4.0
	Maximum	.7	.2	—	—	—	3.2	1.7	1.3	7.4	5.8	17.0	5.6
	Average	.3	.1	—	—	—	2.0	1.1	1.0	2.6	3.2	7.6	2.4
	Minimum	.1	.1	—	—	—	.7	.4	.7	.5	.5	2.0	.7
55	Number	5.0	1.0	6.0	3.0	2.0	5.0	4.0	5.0	3.0	—	2.0	4.0
	Maximum	1.1	.7	2643.7	5.5	425.5	2.3	1.1	.7	.6	—	5.4	7.7
	Average	.6	.7	740.4	3.8	213.6	1.6	.7	.4	.5	—	2.9	4.7
	Minimum	.2	.7	.6	2.7	1.7	.8	.3	.2	.3	—	.4	2.8
56	Number	4.0	1.0	—	—	—	—	—	—	—	—	—	—
	Maximum	4.8	1.5	—	—	—	—	—	—	—	—	—	—
	Average	3.0	1.3	—	—	—	—	—	—	—	—	—	—
	Minimum	1.5	1.5	—	—	—	—	—	—	—	—	—	—
57	Number	—	1.0	1.0	—	5.0	2.0	2.0	3.0	1.0	1.0	1.0	1.0
	Maximum	—	4.6	2.5	—	7.1	3.7	8.8	5435.0	8.4	5.3	1.9	2.4
	Average	—	4.6	2.5	—	5.2	2.7	8.8	1816.5	8.4	5.3	1.9	2.4
	Minimum	—	4.6	2.5	—	3.6	1.7	8.8	4.2	8.4	5.3	1.9	2.4
58	Number	4.0	4.0	4.0	3.0	6.0	4.0	4.0	3.0	3.0	5.0	3.0	4.0
	Maximum	4.1	1.9	8.7	8.4	24.0	7.7	57.0	6.2	5.1	51.0	26.9	17.9
	Average	2.3	1.7	5.0	5.9	13.3	6.3	27.8	5.7	4.1	17.9	15.9	12.2
	Minimum	.6	1.4	3.4	3.3	6.6	5.5	7.0	4.8	3.3	2.1	9.3	8.7

Beta radioactivity by region and State, 1953 to 1958—Micromicrocuries per cubic meter—Continued

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Rocky Mountain total—Continued												
Wyoming total:												
57 Number	1.0	1.0	1.0	2.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	3.0
Maximum	4.9	2.2	1.2	3.7	10.0	7.5	156.0	24.2	36.1	233.7	2.1	4.9
Average	4.9	2.2	1.2	2.3	4.1	4.9	107.2	14.5	22.2	127.4	1.2	3.6
Minimum	4.9	2.2	1.2	.8	.2	1.4	59.2	4.7	8.2	21.0	.2	2.5
58 Number	2.0	4.0	4.0	2.0	3.0	2.0	3.0	2.0	3.0	3.0	4.0	3.0
Maximum	4.9	2.2	26.0	21.0	16.0	7.2	21.0	7.0	5.8	21.3	15.3	13.8
Average	4.2	1.8	8.5	15.0	11.7	6.2	11.3	6.1	3.7	9.8	9.1	8.9
Minimum	3.5	1.4	1.1	8.9	9.2	5.3	3.6	5.2	2.3	3.9	2.3	5.5
Pacific coast total:												
53 Number	—	—	—	—	—	—	—	—	1.0	8.0	8.0	13.0
Maximum	—	—	—	—	—	—	—	—	.2	.6	.4	.4
Average	—	—	—	—	—	—	—	—	.2	.3	.2	.1
Minimum	—	—	—	—	—	—	—	—	.2	.1	0	0
54 Number	12.0	6.0	8.0	1.0	8.0	3.0	6.0	5.0	8.0	24.0	22.0	9.0
Maximum	.1	.2	.2	.1	5.2	.1	.6	.3	11.0	4.3	18.5	1.6
Average	0	.1	0	.1	1.1	0	.2	.2	2.8	1.2	4.8	.8
Minimum	0	0	0	.1	.1	0	0	.1	.2	0	.2	0
55 Number	6.0	8.0	14.0	14.0	11.0	19.0	12.0	17.0	8.0	1.0	5.0	3.0
Maximum	.5	2.5	1.9	6.0	.8	1.6	.5	.4	.4	.2	3.6	1.2
Average	.2	.5	1.0	1.1	.5	.4	.2	.2	.2	.2	1.5	.8
Minimum	.1	.1	.1	.2	0	0	.1	0	0	.2	.2	.2
56 Number	7.0	6.0	6.0	8.0	12.0	13.0	9.0	14.0	12.0	12.0	7.0	3.0
Maximum	4.1	4.2	18.8	2.6	4.7	3.6	4.3	3.8	5.7	3.8	1.2	.8
Average	2.5	2.0	4.8	1.3	1.5	.9	1.2	.6	3.3	1.8	.7	.7
Minimum	.3	.4	.4	.5	0	.1	.1	0	1.0	.4	.4	.7
57 Number	11.0	10.0	13.0	11.0	36.0	33.0	39.0	32.0	31.0	31.0	38.0	41.0
Maximum	5.6	3.0	5.5	7.3	7.5	380.0	369.1	13.5	83.0	731.9	6.4	6.8
Average	2.0	1.5	2.0	2.7	2.7	31.1	16.3	2.2	10.8	27.5	1.7	1.8
Minimum	.6	.4	.2	.7	.3	.1	.3	.3	.2	.8	.2	.3
58 Number	39.0	41.0	46.0	44.0	45.0	43.0	49.0	41.0	40.0	45.0	44.0	44.0
Maximum	7.7	3.9	36.0	19.0	31.0	19.0	66.0	8.8	6.6	79.9	126.0	35.8
Average	2.2	1.3	6.9	7.0	5.9	3.5	6.8	3.2	2.3	9.3	20.1	9.3
Manimum	.4	.2	.6	1.3	.3	.1	.1	.3	.2	.3	.1	1.7
Alaska total:												
53 Number	—	—	—	—	—	—	—	—	—	1.0	4.0	3.0
Maximum	—	—	—	—	—	—	—	—	—	.2	.4	.1
Average	—	—	—	—	—	—	—	—	—	.2	.3	0
Minimum	—	—	—	—	—	—	—	—	—	.2	.1	0
54 Number	3.0	2.0	1.0	—	—	—	1.0	1.0	3.0	1.0	1.0	2.0
Maximum	0	.1	0	—	—	—	.6	.1	11.0	1.1	4.3	1.3
Average	0	.1	0	—	—	—	.6	.1	4.1	1.1	4.3	1.3
Minimum	0	0	0	—	—	—	.6	.1	.3	1.1	4.3	1.1
55 Number	2.0	2.0	—	2.0	2.0	3.0	2.0	2.0	4.0	1.0	5.0	—
Maximum	.2	.4	—	.4	.1	.4	.5	.2	.3	.2	3.6	—
Average	.2	.4	—	.3	.1	.2	.4	.1	.1	.2	1.5	—
Minimum	.1	.4	—	.2	0	0	.2	0	0	.2	.2	—
56 Number	1.0	3.0	—	4.0	5.0	4.0	3.0	4.0	4.0	4.0	4.0	2.0
Maximum	3.4	3.8	—	2.6	1.8	.4	.4	.2	2.6	1.0	1.2	.8
Average	3.4	1.8	—	1.2	.6	.2	.2	.1	2.0	.8	.9	.8
Minimum	3.4	.4	—	.5	0	.1	.1	.1	1.0	.4	.4	.7
57 Number	1.0	2.0	2.0	2.0	3.0	3.0	5.0	1.0	3.0	2.0	5.0	10.0
Maximum	1.1	1.1	1.0	2.0	1.6	1.4	4.0	.7	4.8	1.4	1.4	1.0
Average	1.1	1.0	.8	2.0	1.2	.7	1.2	.7	2.1	1.2	.9	.7
Minimum	1.1	.8	.5	1.9	.7	.3	.3	.7	.8	1.0	.2	.4
58 Number	4.0	4.0	4.0	5.0	4.0	5.0	4.0	4.0	3.0	8.0	4.0	4.0
Maximum	4.0	3.0	8.1	4.2	5.3	1.8	.8	.6	.4	11.3	4.1	9.6
Average	2.0	1.4	4.1	2.7	2.6	.8	.5	.5	.3	5.3	2.9	5.7
Minimum	.4	.6	.6	1.6	.7	.1	.2	.4	.2	.6	2.2	3.5
Arizona total:												
57 Number	—	—	—	—	3.0	4.0	5.0	5.0	6.0	8.0	6.0	7.0
Maximum	—	—	—	—	7.5	15.4	369.1	13.5	83.0	731.9	6.4	3.5
Average	—	—	—	—	6.2	5.8	101.1	6.5	25.9	98.4	3.3	2.2
Minimum	—	—	—	—	5.0	2.1	13.0	2.2	4.2	.8	1.5	.7
58 Number	3.0	4.0	3.0	3.0	4.0	3.0	4.0	4.0	4.0	1.0	2.0	3.0
Maximum	3.7	3.2	16.0	19.0	31.0	10.0	29.0	8.8	6.6	3.2	68.4	24.1
Average	3.3	2.1	6.9	17.0	14.4	6.9	18.5	7.2	3.8	3.2	66.1	16.5
Minimum	2.7	1.3	1.4	15.0	8.2	5.0	12.0	4.5	1.8	3.2	63.7	11.6
California total:												
53 Number	—	—	—	—	—	—	—	—	—	—	3.0	3.0
Maximum	—	—	—	—	—	—	—	—	—	—	.3	.4
Average	—	—	—	—	—	—	—	—	—	—	.2	.2
Minimum	—	—	—	—	—	—	—	—	—	—	.1	—
54 Number	2.0	3.0	3.0	—	3.0	—	—	—	—	—	—	—
Maximum	.1	.2	.2	—	5.2	—	—	—	—	—	—	—
Average	.1	.1	.1	—	2.5	—	—	—	—	—	—	—
Minimum	.1	.1	—	—	.3	—	—	—	—	—	—	—

Beta radioactivity by region and State, 1953 to 1958—Micromicrocuries per cubic meter—Continued

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Pacific Coast total—Cont.													
California total—Con.													
55	Number	1.0	2.0	11.0	10.0	6.0	12.0	6.0	15.0	3.0	—	—	3.0
	Maximum	.5	2.5	1.9	6.0	.8	.8	.3	.4	.4	—	—	1.2
	Average	.5	1.4	1.1	1.2	.6	.4	.2	.2	.3	—	—	.8
	Minimum	.5	.2	.3	.3	.4	.1	.1	.1	.1	—	—	.2
56	Number	5.0	2.0	2.0	3.0	3.0	2.0	1.0	3.0	1.0	2.0	—	—
	Maximum	4.1	4.2	2.5	1.7	2.4	.9	.2	.9	5.1	3.4	—	—
	Average	2.6	2.6	1.5	1.2	1.4	.6	.2	.4	5.1	3.4	—	—
	Minimum	.3	.9	.4	.5	.7	.2	.2	—	5.1	3.3	—	—
57	Number	5.0	4.0	6.0	3.0	22.0	18.0	18.0	17.0	14.0	12.0	17.0	13.0
	Maximum	5.6	2.1	5.5	7.3	6.9	350.0	27.3	4.1	11.3	4.6	2.5	6.8
	Average	2.5	1.5	2.3	5.2	2.5	20.5	4.3	1.5	4.1	2.8	1.6	2.6
	Minimum	1.0	.8	.2	1.9	.3	.1	.6	.3	1.7	1.0	.8	.4
58	Number	17.0	16.0	19.0	21.0	20.0	20.0	24.0	20.0	19.0	21.0	21.0	21.0
	Maximum	7.7	3.9	36.0	19.0	12.0	5.5	18.0	7.3	5.0	79.9	126.0	35.8
	Average	2.5	1.4	8.5	6.3	5.2	2.8	3.9	3.3	2.6	12.0	29.3	10.5
	Minimum	.6	.6	1.0	1.3	.3	1.3	.1	.3	.7	.3	.5	1.7
Hawaii total:													
56	Number	—	—	—	—	3.0	6.0	1.0	3.0	3.0	3.0	3.0	1.0
	Maximum	—	—	—	—	4.7	3.6	4.3	3.8	4.8	3.8	.5	.7
	Average	—	—	—	—	2.1	1.4	4.3	1.8	3.1	2.0	.5	.7
	Minimum	—	—	—	—	.5	.4	4.3	.4	1.3	.6	.4	.7
57	Number	2.0	4.0	4.0	4.0	4.0	3.0	7.0	5.0	4.0	3.0	5.0	3.0
	Maximum	1.8	3.0	3.7	3.4	3.1	1.9	5.2	1.7	8.6	7.2	2.5	2.4
	Average	1.2	1.7	1.9	1.9	2.6	1.3	2.1	.8	3.2	3.3	.9	1.2
	Minimum	.6	.4	.7	.7	1.7	.6	.4	.3	.2	1.0	.2	.3
58	Number	3.0	4.0	4.0	6.0	3.0	4.0	4.0	2.0	5.0	2.0	4.0	5.0
	Maximum	1.6	3.6	7.9	8.3	6.6	5.8	4.2	2.9	2.8	9.6	8.0	17.1
	Average	1.0	2.0	5.1	4.1	4.8	3.8	3.8	2.8	1.8	6.9	6.0	10.4
	Minimum	.5	.6	1.1	1.5	3.2	2.2	3.1	2.7	1.0	4.2	4.5	6.0
Nevada total:													
57	Number	—	—	—	—	2.0	3.0	2.0	2.0	3.0	2.0	2.0	4.0
	Maximum	—	—	—	—	4.2	380.0	25.0	2.9	54.6	4.4	3.6	2.8
	Average	—	—	—	—	4.0	208.3	15.3	2.7	33.5	3.6	2.6	2.3
	Minimum	—	—	—	—	3.8	1.8	5.5	2.5	9.8	2.8	1.5	1.7
58	Number	2.0	2.0	5.0	3.0	3.0	3.0	5.0	4.0	2.0	6.0	4.0	4.0
	Maximum	4.1	1.8	18.0	17.0	12.0	19.0	66.0	7.0	5.5	64.1	19.6	16.7
	Average	4.0	1.6	6.3	12.8	8.1	9.8	27.1	5.8	4.4	13.0	13.0	11.9
	Minimum	3.8	1.4	1.6	8.4	3.3	5.0	6.5	5.3	3.2	2.0	8.1	6.5
Oregon total:													
53	Number	—	—	—	—	—	—	—	—	1.0	7.0	1.0	7.0
	Maximum	—	—	—	—	—	—	—	—	.2	.6	0	.1
	Average	—	—	—	—	—	—	—	—	.2	.3	0	0
	Minimum	—	—	—	—	—	—	—	—	.2	.1	0	0
54	Number	7.0	1.0	4.0	1.0	5.0	3.0	5.0	4.0	5.0	23.0	21.0	7.0
	Maximum	.1	0	.1	.1	.4	.1	.1	.3	5.0	4.3	18.5	1.6
	Average	0	0	0	.1	.2	0	.1	.2	2.0	1.2	4.8	.6
	Minimum	0	0	0	.1	.1	0	0	.1	.2	0	.2	0
55	Number	3.0	4.0	3.0	2.0	3.0	4.0	4.0	—	1.0	—	—	—
	Maximum	.1	.4	1.1	1.5	.7	1.6	.3	—	.1	—	—	—
	Average	.1	.2	.5	1.0	.5	.6	.2	—	.1	—	—	—
	Minimum	.1	.1	.1	.4	.3	.2	.1	—	.1	—	—	—
56	Number	1.0	1.0	4.0	1.0	1.0	1.0	4.0	4.0	4.0	3.0	—	—
	Maximum	.9	1.1	18.8	1.8	3.1	1.1	3.5	.3	5.7	2.8	—	—
	Average	.9	1.1	6.5	1.8	3.1	1.1	1.3	.3	4.2	1.8	—	—
	Minimum	.9	1.1	.8	1.8	3.1	1.1	.3	.2	1.6	1.1	—	—
57	Number	2.0	—	1.0	2.0	2.0	2.0	2.0	2.0	1.0	3.0	2.0	2.0
	Maximum	3.2	—	2.7	1.5	1.8	.8	1.1	1.1	.9	3.8	1.5	1.9
	Average	2.2	—	2.7	1.2	1.4	.7	.8	.8	.9	2.9	1.2	1.3
	Minimum	1.2	—	2.7	.9	1.0	.6	.5	.4	.9	1.4	.8	.6
58	Number	2.0	4.0	4.0	2.0	5.0	4.0	5.0	4.0	3.0	3.0	6.0	4.0
	Maximum	2.6	1.9	17.0	8.3	12.0	2.5	1.8	1.9	1.6	1.7	5.5	4.1
	Average	2.3	.9	6.2	4.9	4.4	1.4	1.1	1.1	.9	.8	2.3	3.3
	Minimum	2.0	.4	1.1	1.4	1.1	.4	.3	.5	.4	.3	.1	2.3
Washington total:													
57	Number	1.0	—	—	—	—	—	—	—	—	1.0	1.0	2.0
	Maximum	2.1	—	—	—	—	—	—	—	—	2.7	.8	1.2
	Average	2.1	—	—	—	—	—	—	—	—	2.7	.8	.9
	Minimum	2.1	—	—	—	—	—	—	—	—	2.7	.8	.6
58	Number	8.0	7.0	7.0	4.0	6.0	4.0	3.0	3.0	4.0	4.0	3.0	3.0
	Maximum	2.4	1.4	16.0	18.0	10.0	8.0	1.7	1.2	2.4	12.5	11.4	8.4
	Average	1.0	.7	6.1	9.7	5.0	4.2	1.5	.8	2.0	7.3	8.7	5.0
	Minimum	.6	.2	.9	1.9	2.0	1.6	1.2	.5	1.0	1.4	6.6	3.1

Appendix D

"The Occurrence of Strontium-90, Iodine-131, and Other Radionuclides in Milk"

by J. E. Campbell, et al.

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Expanding use of nuclear energy requires an awareness of the manifold ways in which exposure to radiation may occur. This report leads with the occurrence of strontium-90, iodine-131, and other radionuclides in milk, particularly in connection with testing programs in the United States and elsewhere. The need for surveillance and monitoring is emphasized particularly to secure a more exact understanding of the problem.

THE OCCURRENCE OF STRONTIUM-90, IODINE-131, AND OTHER RADIONUCLIDES IN MILK—MAY, 1957, THROUGH APRIL, 1958

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ALTHOUGH man has been exposed to naturally occurring radiation since the beginning of his time on earth, his interest in problems of exposure to radiation has been stimulated in recent years as a result of the expanding use of nuclear energy and the occurrence of fall-out from testing programs of several nations. Recognition of the damaging effects to tissues by ionizing radiation has created a general awareness that relatively brief exposure to high levels of radioactivity may produce acute illness. Of special significance in connection with normal peacetime pursuits is the fact that prolonged contact with much lower levels may generate less immediately recognizable but, none the less real, bodily impairments.

In attempting to arrive at an evaluation of the possible damage associated with such relatively low levels, one of the important steps is the measurement of radioactivity concentrations in the environment, including the determination of specific radionuclides in food, water, and air. When these substances contain measurable amounts of radioactivity, it can be assumed that ingestion and inhalation of them will result in an internal radiation exposure which can be expected to augment any damage caused by external exposure originating from natural as well as other sources, including the medical use of ionizing radiation. Although the dose resulting from internally deposited radioactive materials is exceedingly difficult to measure, maximum permissible concentrations (MPCs) for internally deposited radionuclides have been developed[1, 2] on the basis of certain criteria which are discussed in detail elsewhere.[1, 3, 4]

At the present time, fall-out represents the major source of the hazardous long-lived radionuclides of concern to the general population. These radioactive materials, created as the result of nuclear detonations, are carried to the stratosphere, whence they return slowly to the earth with rain, snow, or dust particles. From the standpoint of health significance, strontium-90 is generally considered to be the most hazardous fission

product because of its long radioactive half-life, its relatively long retention in the body, and its similarity to calcium in terms of metabolic behavior which results in a localization in skeletal tissue, and hence, into close association with the blood-forming organs. Accordingly, much research has been focused on the determination of the concentration of this radionuclide in a variety of products including air particulates, soil, water, bone, and foods.[5, 6]

Among the foods, milk has received the greatest attention, with the result that many groups* throughout the world are currently determining its strontium-90 content. In this regard milk is of particular interest because of its importance as a source of dietary calcium. In the United States, about 80 per cent of the calcium in the national diet is furnished by dairy products.[7] If it were possible to adjust the diet in a manner which would result in all dietary calcium and strontium being procured from deep mineral deposits, the intake of strontium-90 would be negligible, since it is "man-made" and is found only on or near the surface of the earth.[8] On the other hand, the finding that only about a seventh of the strontium-90 ingested by the cow appears in her milk,[9] suggests that man's intake of this isotope would be significantly higher if his sole sources of calcium and strontium were from plant sources. Confirmation of this supposition will require further research.

In addition to the food-monitoring activities associated with strontium-90, many reports have been published separately on the occurrence of other radionuclides such as iodine-131,[10] barium-140,[11] cesium-137,[12-14] and radium-226[15] in foods.

This report summarizes the findings of a Public Health Service laboratory group which has been engaged in determining specific radionuclide activity in milk samples from five areas of the United States. These areas are located in the milksheds serving Sacramento, Salt Lake City, St. Louis, Cincinnati, and New York City. The aims of this project were to develop and simplify methods of radiochemical analysis for milk to make them more suitable for use by state and local health departments, and to conduct a pilot study on the problems of repetitive sampling and the quantitative determination of specific radionuclides in milk from selected metropolitan areas. This study is a part of a broader interest of the Service in environmental analyses for radiological contaminants, including measurement of gross radioactivity as well as specific radionuclides in air, water, soil, selected foods, and a variety of other biological materials.

The problem of radiochemical analysis of foods, especially of milk, is exceedingly complicated, owing to the occurrence in most foods of appreciable amounts of natural radioactivity emanating from potassium-40. Within certain limits, the tissue concentration of this radionuclide does not increase with excessive intake because of the rapid turnover of potassium, and the fact that the body must maintain an essentially constant potassium content. Nevertheless, the specific activity of potassium, 820 $\mu\mu$c per gram, results in a high "background level" with the result that gross activity measurements become of little or no value. Therefore, to make these studies as meaningful as possible, all milk samples secured for study have

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(iii) Lamont Geological Observatory, Columbia University, Palisades, N. Y.
(iv) University of Chicago "Project Sunshine," Chicago, Ill.
(v) U. S. Atomic Energy Commission. Health and Safety Laboratory, New York Operations Office, New York.
(vi) Norwegian Defense Research Establishment, Oslo, Norway.
(vii) Dairy Research Institute, Kiel, Germany.

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been subjected to routine analyses for iodine-131, strontium-90, strontium-89, barium-140, and cesium-137. Unpublished work from our laboratory on milk indicates that these isotopes contribute most of the radioactivity, other than that from natural sources and contribute substantially all of the dosage to man from this source.

Milk was chosen as the first item in our attempts to survey the radioactivity of the food supply because, in addition to its importance in the American diet, the production of milk throughout the country at all seasons of the year offers the practical advantage of permitting a continuous testing program. We are able, therefore, to summarize in this report the results of analyses of monthly milk samples collected over a 12-month period, from May 1, 1957, to April 30, 1958, from the five milksheds mentioned. It should be noted that the recent addition of stations at Atlanta, Austin (Tex.), Chicago, Fargo, and Spokane, has now increased the network to ten sampling points, thereby providing expanded geographic coverage.

Methods

Sampling Procedures

The monthly collection of raw milk samples from specified milksheds serving large urban populations in different regions of the United States presented some difficult problems. That these have been satisfactorily resolved is the result of the excellent cooperation of headquarters and regional office Milk and Food Program personnel of the Public Health Service; state and local health department officials; and members of the dairy industry. In each case, the exact location of the sampling point was chosen after conferences with individuals thoroughly familiar with the dairy industry in that area. In every case, the selection of sampling stations within the milksheds was based upon these criteria:

1. The milk represented in each sample was from a group of farms milking a total of at least 1,000 cows.
2. The number of individual farms was small enough so that collection of collateral field data from each farm was feasible.
3. The milk samples were from a supply that was part of a metropolitan milkshed.
4. The conditions under which the milk was received were such that each sample was representative of the same farms in the production area.

By means of individual farm surveys conducted by local health officers or dairy plant officials, collateral information was collected concerning feeding practices, water supplies, and breeds of cattle typical of each area so that these factors could be evaluated with respect to their role in determining the level of radioactivity in milk. One-gallon samples were collected at monthly intervals from each of the stations. These were preserved with a small amount (4 ml) of 40 per cent formaldehyde and forwarded by air parcel post to the Robert A. Taft Sanitary Engineering Center for radionuclide analysis.

Analytical Procedures

Total Calcium—The calcium content of each sample was determined by the method described by Overmann, et al.[11]

Iodine-131—The iodine-131 concentration was measured by gamma-ray spectrometry, using a 2″ by 2″ sodium iodide (thallium activated) crystal in a dipping probe coupled to a photomultiplier tube and a multichannel pulse-height analyzer. Each measurement was based on the count of 3.5 liters of whole milk, using the same amount of distilled water to estimate background. The influence of the counts due to the gamma activity of potassium-40 and of cesium-137 were then subtracted from the net count at 360 Kev to obtain the count for the iodine-131. This value was converted to absolute units on the basis of calibrations made with known quantities of iodine-131 at the same instrument set-

Table 1—Concentration of long half-lived radionuclides in milk (concentration expressed as $\mu\mu c$/liter)

Month 1957–1958	No. of Weapons* Tests Reported		Milksheds									
	Continental U. S.	Elsewhere	Sacramento		Salt Lake City		St. Louis		Cincinnati		New York City	
			Ce^{137}	Sr^{90}	Ce^{137}	Sr^{90}	Ce^{137}	Sr^{90}	Ce^{137}	Sr^{90}	Ce^{137}	Sr^{90}
Jan.–Apr.	0	11										
May	1	3	31.7	4.5	30.6	4.6	18.0	10.1	26.0	5.5	37.8	4.6
June	4	1	40.6	7.0	52.6	6.4	69.1	12.9	35.8	6.7	30.4	5.1
July	4	0	48.5	3.6	51.0	4.9	61.3	11.0	36.2	5.1	22.8	6.7
Aug.	4	1	78.7	1.9	39.0	4.1	36.4	7.7	40.3	4.4	48.8	6.9
Sept.	7	3	44.2	1.5	154.4	4.3	63.7	9.1	53.3	5.0	69.1	6.1
Oct.	1	3	40.5	1.7	47.2	5.5	65.7	9.7	41.6	7.7	48.4	5.0
Nov.	0	1	48.7	9.6	44.9	4.8	35.1	7.8	36.2	7.0	45.0	5.2
Dec.	0	1	33.3	5.0	35.4	3.0	48.9	7.1	41.3	5.9	40.2	5.0
Jan.	•	0	43.6	5.9	38.5	3.0	41.1	7.9	48.3	4.1	29.5	5.6
Feb.	0	2	44.2	3.8	65.3	2.2	44.7	7.0	55.5	3.9	46.3	5.2
Mar.	0	7	47.9	4.2	79.5	3.0	54.7	10.0	61.6	4.1	50.6	3.9
Apr.	0	2	102.2	10.5	65.0	4.7	61.4	12.3	50.2	6.4	44.3	4.0
Average			50.3	4.9	58.6	4.2	50.0	9.4	43.9	5.5	42.8	5.4

• Compiled from various press releases.

tings. The precision of this method was found to be about ± 60 $\mu\mu$c of iodine-131. The amount of iodine-131 in each sample was then corrected for decay during the interval between collection and analysis of the milk.

Strontium-89, Strontium-90, Barium-140, and Cesium-137—To one liter of milk were added carrier quantities of nonradioactive strontium, barium, and cesium, and the mixture was quantitatively ashed by a rapid technic involving constant flow of the milk into a rotating heated crucible where charring occurred quickly.[17] Ashing was completed in a muffle furnace within a few hours. Strontium and barium were separated from the calcium, potassium, and other interfering substances by fractionation of the milk ash with 60-65 per cent HNO_3. The barium was then separated from the strontium as an insoluble $BaCrO_4$ in a buffered acetate solution at pH 5, leaving the strontium in solution. The $BaCrO_4$ was then washed and placed on planchets for counting. The strontium in solution was precipitated as $SrCO_3$ and purified by two scavenging steps, first with $Fe(OH)_3$ and second with a mixture of $Ce(OH)_3$ and $Zr(OH)_4$. The purified $SrCO_3$ was then allowed to stand for two weeks to achieve secular equilibrium with the yttrium-90, and the latter was removed from the parent by a solvent extraction with thenoyl trifluoroacetone at pH 5. Yttrium-90 was recovered from the organic solvent by back extraction with 1 N HNO_3,[18] which was then evaporated in a stainless steel planchet for determination of the yttrium-90 activity. After two weeks "in-growth," the activity of yttrium-90 is 97 per cent of that of the strontium-90 present. During the early stages of the project, yttrium-90 determinations were made with a shielded internal proportional counter. Recently, however, more sensitive instrumentation has become available and the results presented in this paper have been redetermined by the use of a low background anticoincidence counter. The remaining aqueous solution, after the removal of yttrium-90, contained both strontium-90 and strontium-89 which were then precipitated as $SrCO_3$ for determination of total radioactive strontium by beta counting in a shielded internal proportional counter. The concentration of strontium-89 was determined by subtracting the strontium-90 concentration from that obtained for the total radioactive strontium.

From the HNO_3 supernatant, obtained after removal of strontium and barium, cesium was freed of interfering substances by precipitation with ammonium phosphomolybdate. The volume of this precipitate made it unsuitable for counting; therefore, it was converted to $Cs_3Co(NO_2)_6$ which was placed on a planchet, and the beta activity was determined in a shielded internal proportional counter.

The observed activity for each radionuclide, obtained as counts/minute, was converted to $\mu\mu$c/liter after the initial count was corrected for the effect of counter geometry, backscatter, and self-absorption as described by Nader, et al.,[19] and for average chemical recovery of the method. Since barium-140 has a half-life of only 12.8 days, these values were also corrected for decay to time of collection. Recovery studies on milk ash indicate the reliability of the methods for each radionuclide at the average reported value is as follows: strontium-89, ± 3.6 per cent; strontium-90, ± 14.5 per cent; barium-140, ± 4.5 per cent; and cesium-137, ± 4.3 per cent. In the case of cesium, however, the error may be in excess of this amount as a result of volatilization during ashing of the sample.

For the most part, the above procedures represent modification of several recognized chemical and radiochemical technics.[20-24]

The changes have been made princi-

Table 2—Concentration of short and intermediate half-lived radionuclides in milk (concentration expressed as $\mu\mu c$/liter)

Month 1957–1958	No. of Weapons* Tests Reported: Continental U. S.	Elsewhere	Milksheds: Sacramento 1131	Sacramento Ba140	Sacramento Sr89	Salt Lake City 1131	Salt Lake City Ba140	Salt Lake City Sr89	St. Louis 1131	St. Louis Ba140	St. Louis Sr89	Cincinnati 1131	Cincinnati Ba140	Cincinnati Sr89	New York City 1131	New York City Ba140	New York City Sr89
Jan.-Apr.	0	11															
May	1	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
June	4	1	250	—	—	440	71.5	—	410	94.7	—	370	—	—	40	—	—
July	4	0	—	10.8	—	—	197.9	—	—	146.8	—	—	—	—	—	—	—
Aug.	4	1	10	9.6	26.2	200	46.3	71.7	210	51.3	79.3	230	98.8	87.3	50	76.4	74.0
Sept.	7	3	10	25.0	14.1	740	83.0	55.6	970	532.0	243.2	430	125.8	66.4	300	125.9	84.1
Oct.	1	3	20	43.3	21.7	990	130.8	90.5	890	120.9	141.9	300	68.5	131.7	250	158.8	122.0
Nov.	0	1	0	46.9	9.2	0	5.1	23.5	0	8.3	66.4	0	13.3	48.9	100	3.5	37.4
Dec.	0	1	0	25.7	21.4	50	3.5	11.1	0	16.4	29.5	0	3.5	12.3	0	0	14.1
Jan.	0	0	0	0	0	0	1.3	8.6	0	6.0	25.5	0	0	0.3	0	0	5.5
Feb.	0	2	0	8.2	2.9	40	0.5	8.1	0	4.1	14.8	0	1.7	8.5	0	8.7	3.4
Mar.	0	7	0	6.4	17.6	0	0.3	3.3	0	4.6	19.1	0	1.7	5.6	0	0.9	2.6
Apr.	0	2	10	20.8	77.4	30	0	2.2	100	50.2	35.5	30	0	13.1	50	0	2.0
Average			30.0	19.7	21.2	249	49.1	30.5	258	91.1	72.8	136	34.8	41.5	79	41.6	36.1

* Compiled from various press releases.

pally for the purpose of simplifying the technics to make them suitable for surveillance purposes. A major advance in this regard has been the development of a rapid ashing technic in which a one-liter sample of milk can be ashed quantitatively in about two and a half to three hours. With adequate equipment, a technician can reduce six to eight samples to ash in one work day. Details of the above analytical procedures and the rapid ashing technic will be published elsewhere.

Results

For convenience in presenting the results, the radionuclides investigated in this study have been divided into two groups based on their half-lives. The first group consists of cesium-137 and strontium-90 with half-lives of 33 and 28 years, while the second group consists of iodine-131, barium-140, and strontium-89 with half-lives of 8.1, 12.8, and 53 days, respectively.

In Table 1 are summarized the concentrations of the long half-lived radionuclides determined in monthly milk samples received from New York City, Cincinnati, St. Louis, Salt Lake City, and Sacramento milksheds between May 1, 1957, and April 30, 1958, along with the number of publicly reported weapons tests[11] during the same 12-month period. An analysis of variance applied to these data demonstrated that the variability in concentration of cesium-137 was sufficiently great that no significant differences were observed in its concentration either between months or by geographical location. The concentration of strontium-90 also showed no significant variation when analyzed by month; but when viewed by geographical location, the samples from the St. Louis milkshed were found to contain somewhat higher concentrations of strontium-90 than those collected from other milksheds and this difference was found to be statistically significant. Inspection of these data reveals no clear association between the concentrations of strontium-90 or cesium-137 and the publicly announced number of weapons tests per month, with respect to those conducted in the continental limits of the United States or those carried out elsewhere.

Analytical results for the short half-lived radionuclides, iodine-131, barium-140, and strontium-89, are shown in Table 2. In contrast to the finding with strontium-90 and cesium-137, there is a positive correlation between the announced number of nuclear weapons tests conducted in the United States and the occurrence of high concentrations of these radionuclides in milk from all stations, with the exception of Sacramento. This relationship should not be regarded as precise, because the date of sample collection and weapons tests varied independently, thus making it possible for the effect of a given detonation to be observed in a following month. Neither is any information presented regarding the magnitude of the explosions in the various tests. One explanation for the seemingly anomalous results on milk from the Sacramento area might reside in the fact that the prevailing west-to-east movement of air over the United States could carry fall-out from the Nevada test area away from Sacramento. If such be the case, most of the short half-lived isotopes circling the globe would have decayed or dispersed before returning to the Sacramento area.

The relationship which the levels of iodine-131 bear to the dates of continental weapons tests appears to be a direct one. For all stations, except Sacramento, the concentrations of iodine-131 were relatively high during the summer and fall when continental nuclear weapons tests were being conducted.

Similar findings were obtained concerning barium-140 and strontium-89, except that the rates of increase and de-

Table 3—Calcium content of milk samples (grams/liter)

Month 1957–1958	Milksheds				
	Sacramento	Salt Lake City	St. Louis	Cincinnati	New York City
May	1.127	1.114	1.200	1.146	1.008
June	1.092	1.120	1.204	1.151	1.047
July	1.102	1.115	1.199	1.138	1.034
Aug.	1.114	1.125	1.200	1.142	1.038
Sept.	1.090	1.126	1.204	1.157	1.033
Oct.	1.141	1.167	1.273	1.222	1.116
Nov.	1.146	1.172	1.298	1.192	1.101
Dec.	1.157	1.165	1.313	1.162	1.116
Jan.	1.167	1.164	1.317	1.180	1.123
Feb.	1.123	1.092	1.310	1.154	1.092
Mar.	1.149	1.155	1.273	1.080	1.047
Apr.	1.146	1.131	1.244	1.144	1.078
Average	1.130	1.137	1.253	1.156	1.069

crease were more gradual, especially in the case of strontium-89. These differences are not unexpected if the respective half-lives of these two radionuclides are taken into account. Statistical analyses of these data indicated significant differences in concentrations of these two radionuclides both by month and geographical location. Milk samples from the Sacramento area contained less barium-140 and strontium-89 than samples from any other collecting point. Samples collected from the other locations during the period of July through September contained greater quantities of barium-140 than during the other months. The St. Louis samples were also found to contain higher concentrations of barium-140 than those from either Salt Lake City, Cincinnati, or New York City. The strontium-89 content of the samples was greatest during the months of August through October, and again the samples from St. Louis were found to have higher concentrations than any of the other milksheds.

A probable explanation for the observed differences in the influence of individual weapons tests on the long and short half-lived fission products is that the short half-lived products decay to very low values between periods of weapons testing; whereas, the long half-lived products become mixed in the stratospheric reservoir of these materials from previous tests, thereby producing a relatively homogeneous fall-out.

As yet we can offer no satisfactory explanation for the differences observed in concentrations of radionuclides between the milk samples from St. Louis and other areas. Preliminary attempts have been made to account for these differences in terms of farming practices, sources of water, food supplies, breeds of cattle, rainfall, and other factors. As yet, none of these appears to show any substantial relation.

The calcium content of all milk samples is given in Table 3 so that $\mu\mu c$ of strontium-90 per gram of calcium (strontium units) may be calculated. An analysis of variance applied to these data indicates significant differences between month and geographical location, with samples from St. Louis higher than the mean value, 1.149 grams per liter, and the New York City samples lower. Although there is an apparent relationship between the concentrations of strontium-89, strontium-90, and barium-140 and the high calcium content of the milk

from the St. Louis milkshed, additional work is needed to establish the existence of a cause-and-effect relationship.

Discussion

One basis for evaluating the significance of these data is to compare them to the MPCs of radionuclides established for water.[1, 2] These values can be applied to foodstuffs if the units be changed from μc/ml to μc/g (wet weight).[3] An MPC for any given radionuclide may be defined as that concentration which, if continually ingested or inhaled, will result in the maximum permissible exposure to the critical organ. The factors involved in arriving at these values are numerous and complicated, and they are not included here, owing to the limitations of space plus the fact that they have been adequately discussed elsewhere.[1, 3, 4] It should be emphasized, however, that the MPC values were originally calculated on the basis of occupational exposure (equivalent either to an acceptable x-ray dose or to an acceptable body burden of radium-226) and have been subsequently adapted as standards for the general population by the application of appropriate factors. Although the current MPCs[1] represented the best collective judgment of the National Committee on Radiation Protection at the time of their publication in 1953, it was generally recognized that the problem of establishing a basic formula for determining precisely the maximum permissible limits of exposure would require many years of further study.

More recent deliberations by the National Committee on Radiation Protection and the International Commission on Radiological Protection have tended to favor more conservative MPCs, such as the tentative values given in NBS Handbook 66 for occupational exposure.[3,4] In view of this trend, the forthcoming revision of Handbook 52 may contain lower numerical values for the MPCs applicable to the general population than those of the present edition.

Hence, extant MPC values, as well as any variations that may appear in the foreseeable future, must be considered tentative and subject to changes resulting from the accumulation of new knowledge. Therefore, the recommended values constitute only a rough guide to action by public health administrators, pending the development of solid evidence to provide a firm basis for standards.

To enable public health workers to make a preliminary estimate of the possible hazard associated with long-term use of milk at the present level of radioactivity, the average values for individual radionuclides from each sampling point have been expressed as percentages of their MPCs, which are presented in Table 4. These data reveal that the radionuclide of greatest potential hazard in milk is strontium-90, followed by iodine-131, while all of the other radio-

Table 4—Average radionuclide contribution of milk expressed as a per cent of maximum permissible concentration for the general population[1, 2]

Radionuclide	MPC ($\mu\mu c$/liter)	Milksheds				
		Sacramento	Salt Lake City	St. Louis	Cincinnati	New York City
Sr90	80	6.2	5.3	11.7	6.9	6.8
I131	3,000	1.0	8.3	8.6	4.5	2.6
Sr89	7,000	0.3	0.4	1.3	0.6	0.6
Cs137	150,000	0.03	0.04	0.03	0.03	0.03
Ba140	200,000	0.01	0.02	0.05	0.02	0.02

nuclides may be regarded as relatively unimportant. A direct comparison of the concentrations in milk with the MPCs of these radionuclides does not necessarily allow an accurate evaluation of the contributions made by milk. It will be recalled that the MPC (for water) is defined as that concentration which, if ingested continuously, will result in the maximum permissible exposure to the critical organ. In these calculations, an intake of 2.2 liters of water per day is assumed.[1] If the MPC for strontium-90 be multiplied by the daily water intake, the result is a maximum daily allowable amount of strontium-90 which is 176 $\mu\mu$c.

In the United States, the daily consumption of milk, or its equivalent in dairy products, is quite variable among different segments of the population, but generally is much less than 2.2 liters. If an individual consumes an average of one quart per day which contains 6 $\mu\mu$c of strontium-90, he will receive from milk about 3.3 per cent of the maximum permissible amount of strontium-90 instead of approximately 7.5 per cent as would be indicated by direct calculation from the MPC. Similarly, assuming this quart of milk also contained 150 $\mu\mu$c iodine-131, he will then receive 2.3 per cent of the maximum allowable amount of iodine-131 from this source rather than 5.0 per cent.

Since milk forms only one part of the diet for most people, it is clear that radioactivity levels in milk are not necessarily an indicator of total dietary exposure. Although evidence suggests that strontium-90 from milk may represent a substantial portion of the total intake of this radionuclide in the United States, generalization on the contributions of milk to total radiation exposure are not warranted until additional evidence is available regarding the concentration of strontium-90 and the other biologically important radionuclides in foods generally.

Summary and Conclusions

Data are presented giving concentrations of iodine-131, strontium-89, strontium-90, barium-140, and cesium-137 in monthly milk samples from selected milksheds serving Sacramento, Salt Lake City, St. Louis, Cincinnati, and New York City during the period from May, 1957, through April, 1958.

The concentrations of iodine-131, barium-140, and strontium-89 varied widely, the higher levels being closely associated with the number of nuclear weapons tests per month in the United States, while tests conducted elsewhere in the world had a noticeable but lesser effect on the values observed. On the other hand, cesium-137 and strontium-90 were found not to be correlated with the number of concurrent weapons tests. Samples from each geographical area contained fairly consistent amounts of these two fission products. The samples from the St. Louis milkshed collected to date contained higher concentrations of strontium-90, strontium-89, and barium-140 than those collected from other areas. Although these differences were relatively small, they were found to be statistically significant. There is no completely satisfactory explanation to account for these findings. These differences emphasize the need for more intensive studies concerning the factors influencing levels of radionuclides in milk.

A comparison of the observed concentrations of the radionuclides in milk with their MPCs[1, 2] indicates a need to continue radiation surveillance (studies) on milk, dairy products, and other foods, in order to determine the contribution made by these substances to over-all radiation exposure. The data demonstrate sufficient variations in radioactivity, with respect to time and geographical location, to emphasize further the need for continued monitoring in order to secure a more exact understanding of the problems involved.

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Appendix E

Report on Radioactivity in Milk (1957-1959)

(See also vol. 3, app. B)

National Milk Surveillance Network

U. S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
Public Health Service
Washington 25, D. C.

FOR RELEASE
Monday, April 13, 1959 HEW-J80

The Public Health Service reported today on the levels of radioactivity in milk collected during January 1959 from 10 sampling stations across the country.

The milk sampling network is part of the Service's program of measurement of radioactivity in air, water, and food. Milk was chosen for the initial study of specific isotopes because it is the most practical to sample and is produced throughout the year in all sections of the country.

Both the monthly levels and the yearly averages for all radioisotopes in the milk samples remained below the levels which the National Committee on Radiation Protection and Measurements recommends as permissible for lifetime exposure by the general population.

The levels of radioactivity in the January samples continued the see-saw pattern that has prevailed from the beginning of the study in the spring of 1957.

Average levels over a considerable period of time are far more significant from a public health standpoint than fluctuating monthly levels, the Public Health Service pointed out.

Levels recommended as permissible for lifetime exposure, the Service noted, may be exceeded by varying amounts and for varying periods without causing appreciable harm to the individual.

The permissible lifetime level for strontium-90, one of the five radioisotopes identified in the milk samples is currently set at 80 micro-microcuries per liter. A curie is a measure of radioactivity equivalent to that produced by one gram of radium, and a micromicrocurie is one millionth of a millionth of a curie.

Average levels of strontium-90 for the five stations which were in operation for the full 12-month period ending January 1959 were:

Cincinnati, Ohio, 9.1 micromicrocuries per liter; New York, New York, 6.6 uuc/liter; Sacramento, California, 5.0 uuc/liter; Salt Lake City, Utah, 4.4 uuc/liter; St. Louis, Missouri, 14.1 uuc/liter.

Strontium-90 levels for January were as follows:

Atlanta -- 13.4 micromicrocuries per liter; Austin -- 5.7; Chicago -- 6.7; Cincinnati -- 11.7; Fargo-Moorhead -- 12.3; New York -- 6.9; Sacramento -- 4.3; Salt Lake City -- 4.5; Spokane -- 9.1; and St. Louis -- 18.6.

Levels for the other isotopes found in the milk samples -- iodine-131, strontium-89, barium-140, and cesium-137 -- have consistently been only a fraction of the permissible levels for these isotopes.

The levels currently recommended by the National Committee on Radiation Protection and Measurement as permissible for the general population have their origin in occupational exposure limits for individuals working with radioactive materials in industry and research.

The levels recommended as permissible for the general public are far lower than those considered permissible for persons working with radioactive materials, since the duration or amount of exposure of such persons is more subject to controls than would be the case with the general population.

The complete data for January together with 12-month averages for the five oldest stations are shown on the attached tables.

Table 1 Analysis Summary of Samples Collected in January 1959 From Milksheds Serving Specified Areas (Micromicrocuries per liter)

Area	Calcium grams/liter	Iodine^{131}	Strontium^{89}	Strontium^{90}	Barium^{140}	Cesium^{137}
(Permissible Limits* Recommended by NCRP&M for Lifetime Exposure)		(3,000*)	(7,000*)	(80.0*)	(200,000*)	(150,000*)
Atlanta, Ga.	1.242	7	62	13.4	8	84
Austin, Texas	1.216	6	27	5.7	2	39
Chicago, Ill.	1.131	4	6	6.7	0	64
Cincinnati, Ohio	1.141	2	33	11.7	4	55
Fargo, N. Dak.-Moorhead, Minn.	1.159	2	27	12.3	1	67
New York, N.Y.	1.060	0	10	6.9	3	65
Sacramento, Calif.	1.150	0	15	4.3	0	35
Salt Lake City, Utah	1.137	2	6	4.5	5	34
Spokane, Washington	1.268	7	20	9.1	3	73
St. Louis Mo.	1.329	7	77	18.6	14	64

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being applicable to milk.

MILK SAMPLES

Table 2 Yearly Average Levels for Period Ending January 1959
in micromicrocuries per liter

Area	Calcium grams/liter	Iodine^{131}	Strontium^{89}	Strontium^{90}	Berium^{140}	Cesium^{137}
(Permissible Limits* Recommended by NCRP&M for Lifetime Exposure)		(3,000*)	(7,000*)	(30.0*)	(200,000*)	(150,000*)
Cincinnati, Ohio	1.142	33	68	9.1	24	64
New York, N. Y.	1.092	28	37	6.6	15	61
Sacramento, Calif.	1.131	31	26	5.0	7	57
Salt Lake City, Utah	1.140	31	23	4.4	7	49
St. Louis, Missouri	1.268	83	134	14.1	49	84

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being applicable to milk.

Released April 1959

Released April 1959

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

Radioactivity in Milk

Results of Composite Samples from ATLANTA, GEORGIA Milkshed
for period ending January 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
						AVAILABLE TO DATE						
6-2-58	1.164		0		37		13.7		6		118	
7-2	1.158		22		39		10.2		12		111	
8-2	1.188		65		114		11.9		50		103	
9-2	1.154		20		72		13.8		7		79	
10-2	1.220		6		76		10.4		4		77	
11-2	1.193		32		30		8.8		8		56	
12-3	1.214		21		27		10.2		8		72	
1-7-59	1.242		7		62		13.4		8		84	

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

Radioactivity in Milk

Results of Composite Samples from AUSTIN, TEXAS Milkshed
for period ending January 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
						AVAILABLE TO DATE						
6-6-58	1.115		0		26		2.2		1		74	
7-3	1.144		8		15		3.5		5		48	
8-6	1.160		50		40		3.4		18		51	
9-4	1.121		16		32		3.9		6		43	
10-3	1.148		11		35		5.1		0		33	
11-5	1.172		181		49		3.7		30		42	
12-3	1.176		39		32		2.6		12		44	
1-6-59	1.216		6		27		5.7		2		39	

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Public Health Service

Strontium - 89	7,000	"	"	
Strontium - 90	80	"	"	

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Radioactivity in Milk

Results of Composite Samples from CHICAGO, ILLINOIS Milkshed
for period ending January 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
						AVAILABLE TO DATE						
7-16-58	1.069		124		58		7.1		36		112	
8-18	1.098		43		64		9.3		18		88	
9-16	1.161		13		94		7.9		10		71	
10-14	1.123		20		53		6.0		1		55	
11-19	1.141		56		64		8.4		3		64	
12-17	1.103		8		14		7.0		8		71	
1-14-59	1.131		4		6		6.7		0		64	

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from CINCINNATI, OHIO Milkshed
for period ending January 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
2-16-58	1.154		0		8		3.9		2		56	
3-16	1.080		0		6		4.1		2		62	
4-14	1.144	1.156	30	135	13	42	6.4	5.5	0	35	50	44
5-13	1.161	1.158	0	123	70	44	8.6	5.8	16	33	50	46
6-16	1.227	1.164	0	89	106	50	11.6	6.2	36	33	78	51
7-20	1.082	1.159	107	91	194	62	13.0	6.8	112	40	96	54
8-13	1.102	1.155	42	76	97	63	7.5	7.1	84	39	84	58
9-19	1.132	1.153	5	40	98	65	9.4	7.4	13	29	59	58
10-16	1.175	1.149	31	18	56	59	8.6	7.5	8	24	53	59
11-14	1.157	1.146	177	33	108	64	15.2	8.2	10	24	64	61
12-22	1.148	1.145	8	33	37	66	9.6	8.5	4	24	63	63
1-15-59	1.141	1.142	2	33	33	68	11.7	9.1	4	24	55	64

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000	"	"	
Strontium - 90	80	"	"	
Cesium - 137	150,000	"	"	

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Radioactivity in Milk

Results of Composite Samples from FARGO, N. D.--Moorhead, Minn., Milkshed
for period ending January 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
						AVAILABLE TO DATE						
6-7-58	1.112		30		80		15.6		18		110	
7-6	1.108		92		142		16.3		47		147	
8-3	1.116		48		53		10.2		14		96	
9-4	1.125		27		140		14.1		53		113	
10-1	1.215		20		161		15.0		16		67	
10-30	1.166		86		53		11.5		28		56	
12-4	1.165		0		31		12.3		0		77	
12-31	1.159		2		27		12.3		1		67	

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from New York, N.Y., Milkshed
for period ending January 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
2-15-58	1.092		0		3		5.2		9		46	
3-15	1.047		0		3		3.9		1		51	
4-15	1.078	1.077	50	79	2	38	4.0	5.4	0	42	44	43
5-15	1.036	1.072	32	74	23	37	3.6	5.3	5	38	40	43
6-17	1.093	1.076	0	71	63	39	9.9	5.7	20	36	71	46
7-15	1.062	1.078	67	71	84	43	10.5	5.9	64	39	83	51
8-15	1.048	1.079	69	72	41	40	3.3	5.6	28	35	67	53
9-15	1.241	1.096	10	48	73	39	5.6	5.6	15	25	76	53
10-15	1.141	1.098	61	32	85	36	9.5	5.9	14	13	53	54
11-15	1.089	1.097	35	27	55	38	8.8	6.2	30	15	67	56
12-15	1.114	1.097	9	28	11	37	7.9	6.5	0	15	71	58
1-16-59	1.060	1.092	0	28	10	37	6.9	6.6	3	15	65	61

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000 " "	Cesium - 137	150,000 " "	
Strontium - 90	80 " "			

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Radioactivity in Milk

Results of Composite Samples from SACRAMENTO, CALIFORNIA Milkshed
for period ending January 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
2-16-58	1.123		0		3		3.8		8		44	
3-16	1.149		0		18		4.2		6		48	
4-14	1.146	1.130	10	30	77	21	10.5	4.9	21	20	102	50
5-15	1.141	1.131	0	27	38	23	3.8	4.8	12	19	54	55
6-15	1.122	1.133	240	26	40	24	7.1	4.8	6	18	79	58
7-13	1.036	1.128	45	28	20	24	3.3	4.9	7	18	53	56
8-17	1.150	1.131	22	29	24	24	6.8	5.3	0	17	65	55
9-17	1.161	1.137	9	29	17	24	3.8	5.5	0	15	72	57
10-14	1.109	1.134	12	28	11	23	1.4	5.4	1	11	39	57
11-18	1.111	1.131	17	30	18	24	6.1	5.1	14	8	46	57
12-14	1.166	1.132	14	31	10	25	4.2	5.1	6	7	48	58
1-15-59	1.150	1.131	0	31	15	26	4.3	5.0	0	7	35	57

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from SALT LAKE CITY, UTAH Milkshed
for period ending January 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
2-17-58	1.092		40		8		2.2		0		65	
3-13	1.155		0		3		3.0		0		80	
4-14	1.131	1.137	30	249	2	30	4.7	4.2	0	49	65	59
5-14	1.142	1.140	0	226	26	30	3.3	4.1	8	46	42	60
6-11	1.129	1.140	0	186	68	33	7.3	4.2	21	41	59	60
7-15	1.068	1.136	156	184	26	33	4.7	4.2	16	26	40	59
8-14	1.108	1.135	77	174	44	31	4.2	4.2	20	24	43	59
9-13	1.207	1.142	14	113	44	30	5.0	4.2	14	18	48	51
10-13	1.187	1.143	11	32	26	24	3.1	4.0	5	8	31	49
11-14	1.162	1.142	33	34	13	23	5.2	4.1	4	8	37	49
12-16	1.161	1.142	8	31	5	23	6.1	4.3	0	7	39	49
1-15-59	1.137	1.140	2	31	6	23	4.5	4.4	5	7	34	49

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Iodine - 131 3,000 uuc/liter
Strontium - 89 7,000 " "
Strontium - 90 80 " "
Barium - 140 200,000 uuc/liter
Cesium - 137 150,000 " "

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Radioactivity in Milk

Results of Composite Samples from SPOKANE, WASHINGTON Milkshed
for period ending January 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
						AVAILABLE TO DATE						
8-8-58	1.168		68		64		6.9		18		93	
9-3	1.163		11		43		8.2		5		78	
10-2	1.202		8		53		8.6		8		72	
11-6	1.223		67		35		11.9		52		72	
11-30	1.241		30		21		8.6		7		84	
1-2-59	1.268		7		20		9.1		3		73	

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131 3,000 uuc/liter
Strontium - 89 7,000 " "
Strontium - 90 80 " "
Barium - 140 200,000 uuc/liter
Cesium - 137 150,000 " "

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

Radioactivity in Milk

Results of Composite Samples from ST. LOUIS, MO. Milkshed
for period ending January 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
2-17-58	1.310		0		15		7.0		4		45	
3-18	1.273		0		19		10.0		5		55	
4-16	1.244	1.252	100	258	36	73	12.3	9.4	50	94	61	50
5-20	1.259	1.257	0	234	107	76	10.0	9.4	14	88	94	56
6-18	1.217	1.258	0	197	122	74	14.8	9.6	44	83	96	59
7-16	1.175	1.257	624	233	306	99	18.7	10.2	229	90	160	67
8-19	1.280	1.264	61	220	263	115	14.1	10.7	113	95	109	73
9-16	1.303	1.272	19	141	283	118	15.4	11.2	48	55	104	76
10-16	1.271	1.272	35	70	138	118	12.2	11.4	14	46	71	77
11-18	1.280	1.270	123	80	168	126	20.1	12.5	36	48	74	80
12-16	1.274	1.267	23	82	84	130	15.6	13.2	8	48	75	82
1-17-59	1.329	1.268	7	83	77	134	18.6	14.1	14	49	64	84

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

U. S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
Public Health Service
Washington 25, D. C.

FOR IMMEDIATE RELEASE
Monday, July 13, 1959 HEW-K70

The Public Health Service reported today on the levels of radioactivity in milk collected during April from twelve sampling stations across the country.

Both the monthly levels and the longer-term averages for all radioactive isotopes analyzed in the milk samples from all stations remained below the levels which the National Committee on Radiation Protection and Measurements currently suggests as permissible for life-time exposure by the general population.

The levels of radioactivity in the April samples continued the fluctuating pattern that has prevailed from the beginning of the study in 1957 with the exception of St. Louis.

Milk samples from the St. Louis Area showed a strontium 90 count of 37.3 micromicrocuries per litre during the month. Although still below the maximum permissible level of 80 micromicrocuries for a life-time exposure for the general population set by the National Committee on Radiation Protection and Measurements, this is the highest recorded for the two-year period in St. Louis.

The reason for the consistently higher levels which have prevailed in St. Louis over the two-year period has not clearly been determined, according to the Public Health Service. The location of weapons testing sites in relation to the meteorological pattern of winds and rain in the area, however, is believed by some scientists to be a principal factor.

A gradual general rise in strontium 90 levels over the next six years is to be anticipated as a result of weapons testing conducted to date.

(More)

These levels, the Service noted, may be exceeded by varying amounts and for varying periods without causing appreciable harm to the individual.

The milk sampling network is part of the Service's program of measurement of radioactivity in air, water, and food. Milk was chosen for study of specific isotopes in foods because it is the most practical sample and is produced throughout the year in all sections of the country.

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NOTE TO CORRESPONDENTS:

The complete data for April together with average levels for all stations for the period ending April 1959 are shown on the attached tables.

Table 1 HEW-K70

Analysis Summary of Samples Collected
in April 1959 From Milksheds Serving Specified Areas
(Micromicrocuries per liter)

Area	Iodine 131	Strontium 89	Strontium 90	Barium 140	Cesium 137
Permissible Limits* Lifetime Exposure (MCRP&M)	3,000*	7,000*	80.0*	200,000*	150,000*
Atlanta, Ga.	3	131	20.8	0	114
Austin, Texas	0	67	8.9	0	60
Chicago, Ill.	3	7	7.2	0	64
Cincinnati, Ohio	1	39	16.5	0	63
Fargo, N. Dak.-Moorhead, Minn.	0	10	12.3	0	61
New York, N. Y.	3	7	7.6	0	52
Overton, Nevada	0	4	3.1	0	30
Sacramento, Calif.	4	36	7.5	0	50
Salt Lake City, Utah	5	6	5.4	0	32
Spokane, Washington	0	15	10.5	0	58
St. George, Utah	0	6	5.6	0	32
St. Louis, Mo.	0	162	37.3 ~~37.3~~	0	100

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being applicable to milk.

Table 2 HEW-K70

Milk Samples
Average Levels for Period Ending April 1959
(Micromicrocuries per liter)

Area	No. Mos.	Iodine 131	Strontium 89	Strontium 90	Barium 140	Casium 137
Permissible Limits* Lifetime Exposure (MCRP&M)		3,000*	7,000*	80.0*	200,000*	150,000*
Atlanta, Ga.	11	17	68	12.2	9	90
Austin, Texas	11	29	39	4.8	7	50
Chicago, Ill	10	28	37	7.1	8	72
Cincinnati, Ohio	12	32	73	11.4	24	66
Fargo, N. Dak.- Moorhead, Minn.	11	29	66	13.1	16	84
New York, N. Y.	12	24	39	7.2	15	63
Sacramento, Calif.	12	31	25	5.0	4	54
Salt Lake City, Utah	12	26	25	4.7	8	40
Spokane, Washington	9	23	30	9.0	10	76
St. Louis, Mo.	12	75	160	18.2	44	95

*These limits are the maxima permissionable limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being applicable to milk.

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DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

Radioactivity in Milk

Results of Composite Samples from ATLANTA, GEORGIA, Milkshed
for period ending April 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average
						AVAILABLE TO DATE						
6-2-58	1.164		0		37		13.7		6		118	
7-2	1.158		22		39		10.2		12		111	
8-2	1.188		65		114		11.9		50		103	
9-2	1.154		20		72		13.8		7		79	
10-2	1.220		6		76		10.4		4		77	
11-2	1.193		32		30		8.8		8		56	
12-3	1.214		21		27		10.2		8		72	
1-7-59	1.242		7		62		13.4		8		84	
2-3	1.218		5		62		7.3		0		80	
3-3	1.246		4		100		14.0		0		98	
4-7	1.181	1.198	3	17	131	68	20.8	12.2	0	9	114	90

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Public Health Service

Radioactivity in Milk

Results of Composite Samples from AUSTIN, TEXAS, Milkshed
for period ending April 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average
						AVAILABLE TO DATE						
6-6-58	1.115		0		26		2.2		1		74	
7-3	1.144		8		15		3.5		5		48	
8-6	1.160		50		40		3.4		18		51	
9-4	1.121		16		32		3.9		6		43	
10-3	1.148		11		35		5.1		0		33	
11-5	1.172		181		49		3.7		30		42	
12-3	1.176		39		32		2.6		12		44	
1-6-59	1.216		6		27		5.7		2		39	
2-5	1.153		10		37		6.3		3		49	
3-4	1.169		2		68		7.3		0		62	
4-7	1.158	1.157	0	29	67	39	8.9	4.8	0	7	60	50

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000	" "
Strontium - 90	80	" "

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Public Health Service

Radioactivity in Milk

Results of Composite Samples from CHICAGO, ILLINOIS, Milkshed
for period ending April 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	10 Mo. Average	Sample	10 Mo. Average	Sample	10 Mo. Average	Sample	10 Mo. Average	Sample	10 Mo. Average	Sample	10 Mo. Average
						AVAILABLE TO DATE						
7-16-58	1.069		124		58		7.1		36		112	
8-18	1.098		43		64		9.3		18		88	
9-16	1.161		13		94		7.9		10		71	
10-14	1.123		20		53		6.0		1		55	
11-19	1.141		56		64		8.4		3		64	
12-17	1.103		8		14		7.0		8		71	
1-14-59	1.131		4		6		6.7		0		64	
2-16	1.119		8		1		6.3		0		71	
3-17	1.085		5		6		5.5		0		59	
4-10	1.143	1.117	3	28	7	37	7.2	7.1	0	8	64	72

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from CINCINNATI, OHIO, Milkshed
for period ending April 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
5-13-58	1.161	1.158	0	123	70	44	8.6	5.8	16	33	50	46
6-16	1.227	1.164	0	89	106	50	11.6	6.2	36	33	78	51
7-20	1.082	1.159	107	91	194	62	13.0	6.8	112	40	96	54
8-13	1.102	1.155	42	76	97	63	7.5	7.1	84	39	84	58
9-19	1.132	1.153	5	40	98	65	9.4	7.4	13	29	59	58
10-16	1.175	1.149	31	18	56	59	8.6	7.5	8	24	53	59
11-14	1.157	1.146	177	33	108	64	15.2	8.2	10	24	64	61
12-22	1.148	1.145	8	33	37	66	9.6	8.5	4	24	63	63
1-15-59	1.141	1.142	2	33	33	68	11.7	9.1	4	24	55	64
2-26	1.155	1.142	4	34	14	69	12.2	9.8	0	24	60	64
3-18	1.150	1.148	1	34	19	70	12.9	10.6	0	24	61	64
4-15	1.173	1.150	1	32	39	73	16.5	11.4	0	24	63	66

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000	" "
Strontium - 90	80	" "

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Public Health Service

Radioactivity in Milk

Results of Composite Samples from FARGO, N. D.—Moorhead, Minn., Milkshed
for period ending April 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average
							AVAILABLE TO DATE					
6-7-58	1.112		30		80		15.6		18		110	
7-6	1.108		92		142		16.3		47		147	
8-3	1.116		48		53		10.2		14		96	
9-4	1.125		27		140		14.1		53		113	
10-1	1.215		20		161		15.0		16		67	
10-30	1.166		86		53		11.5		28		56	
12-4	1.165		0		31		12.3		0		77	
12-31	1.159		2		27		12.3		1		67	
2-4-59	1.135		8		17		11.8		0		61	
3-9	1.109		5		12		12.2		0		67	
4-7	1.163	1.143	0	29	10	66	12.3	13.1	0	16	61	84

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from New York, N.Y., Milkshed
for period ending April 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
5-15-58	1.036	1.072	32	74	23	37	3.6	5.3	5	38	40	43
6-17	1.093	1.076	0	71	63	39	9.9	5.7	20	36	71	46
7-15	1.062	1.078	67	71	84	43	10.5	5.9	64	39	83	51
8-15	1.048	1.079	69	72	41	40	3.3	5.6	28	35	67	53
9-15	1.241	1.096	10	48	73	39	5.6	5.6	15	25	76	53
10-15	1.141	1.098	61	32	85	36	9.5	5.9	14	13	53	54
11-15	1.089	1.097	35	27	55	38	8.8	6.2	30	15	67	56
12-15	1.114	1.097	9	28	11	37	7.9	6.5	0	15	71	58
1-16-59	1.060	1.092	0	28	10	37	6.9	6.6	3	16	65	61
2-16	1.115	1.094	5	28	6	37	6.5	6.7	0	15	59	62
3-16	1.106	1.099	0	28	5	38	6.5	6.9	0	15	55	63
4-15	1.109	1.101	3	24	7	39	7.6	7.2	0	15	52	63

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000	"	"	
Strontium - 90	80	"	"	
Cesium - 137	150,000	"	"	

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Radioactivity in Milk

Results of Composite Samples from OVERTON, NEVADA, Milkshed
for period ending April, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
3-15-59	1.098		1		7		4.2		0		31	
4-15	1.094		0		4		3.1		0		30	
						AVAILABLE TO DATE						

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from SACRAMENTO, CALIFORNIA, Milkshed
for period ending April 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
5-15-58	1.141	1.131	0	27	38	23	3.8	4.8	12	19	54	55
6-15	1.122	1.133	240	26	40	24	7.1	4.8	6	18	79	58
7-13	1.036	1.128	45	28	20	24	3.3	4.9	7	18	53	56
8-17	1.150	1.131	22	29	24	24	6.8	5.3	0	17	65	55
9-17	1.161	1.137	9	29	17	24	3.8	5.5	0	15	72	57
10-14	1.109	1.134	12	28	11	23	1.4	5.4	1	11	39	57
11-18	1.111	1.131	17	30	18	24	6.1	5.1	14	8	46	57
12-14	1.166	1.132	14	31	10	25	4.2	5.1	6	7	48	58
1-15-59	1.150	1.131	0	31	15	24	4.3	5.0	0	7	35	57
2-23	1.151	1.133	3	31	12	25	3.9	5.0	0	6	46	57
3-15	1.133	1.131	1	31	58	28	7.7	5.2	0	6	60	58
4-19	1.148	1.132	4	31	36	25	7.5	5.0	0	4	50	54

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000	" "
Strontium - 90	80	" "

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Public Health Service

Radioactivity in Milk

Results of Composite Samples from SALT LAKE CITY, UTAH, Milkshed
for period ending April 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
5-14-58	1.142	1.140	0	226	26	30	3.3	4.1	8	46	42	60
6-11	1.129	1.140	0	186	68	33	7.3	4.2	21	41	59	60
7-15	1.068	1.136	156	184	26	33	4.7	4.2	16	26	40	59
8-14	1.108	1.135	77	174	44	31	4.2	4.2	20	24	43	59
9-13	1.207	1.142	14	113	44	30	5.0	4.2	14	18	48	51
10-13	1.187	1.143	11	32	26	24	3.1	4.0	5	8	31	49
11-14	1.162	1.142	33	34	13	23	5.2	4.1	4	8	37	49
12-16	1.161	1.142	8	31	5	23	6.1	4.3	0	7	39	49
1-15-59	1.137	1.140	2	31	6	23	4.5	4.4	5	8	34	49
2-17	1.176	1.147	1	28	5	22	3.4	4.5	0	8	37	46
3-16	1.176	1.149	2	28	4	22	4.6	4.7	0	8	38	43
4-15	1.118	1.148	5	26	6	23	5.4	4.7	0	8	32	40

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

Radioactivity in Milk

Results of Composite Samples from SPOKANE, WASHINGTON, Milkshed
for period ending April 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	9 Mo. Average	Sample	9 Mo. Average	Sample	9 Mo. Average	Sample	9 Mo. Average	Sample	9 Mo. Average	Sample	9 Mo. Average
						AVAILABLE TO DATE						
8-8-58	1.168		68		64		6.9		18		93	
9-3	1.163		11		43		8.2		5		78	
10-2	1.202		8		53		8.6		8		72	
11-6	1.223		67		35		11.9		52		72	
11-30	1.241		30		21		8.6		7		84	
1-2-59	1.268		7		20		9.1		3		73	
2-3	1.183		4		16		6.3		0		84	
3-2	1.236		8		6		10.9		0		68	
4-6	1.172	1.206	0	23	15	30	10.5	9.0	0	10	58	76

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000	" "
Strontium - 90	80	" "

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Released July 1959

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

Radioactivity in Milk

Results of Composite Samples from ST. GEORGE, UTAH, Milkshed
for period ending April 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
3-20-59	1.161		3		2		6.0		0		33	
4-11	1.104		0		6		5.6		0		32	
						AVAILABLE TO DATE						

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Released July 1959

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

Radioactivity in Milk

Results of Composite Samples from ST. LOUIS, MO., Milkshed
for period ending April 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
5-20-58	1.259	1.257	0	234	107	76	10.0	9.4	14	88	94	56
6-18	1.217	1.258	0	197	122	74	14.8	9.6	44	83	96	59
7-16	1.175	1.257	624	233	306	99	18.7	10.2	229	90	160	67
8-19	1.280	1.264	61	220	263	115	14.1	10.7	113	95	109	73
9-16	1.303	1.272	19	141	283	118	15.4	11.2	48	55	104	76
10-16	1.271	1.272	35	70	138	118	12.2	11.4	14	46	71	77
11-18	1.280	1.270	123	80	168	126	20.1	12.5	36	48	74	80
12-16	1.274	1.267	23	82	84	130	15.6	13.2	8	48	75	82
1-17-59	1.329	1.268	7	83	77	134	18.6	14.1	14	48	64	84
2-17	1.282	1.266	0	83	84	140	19.6	15.1	4	48	73	86
3-16	1.225	1.262	4	83	130	150	22.5	16.2	5	48	92	89
4-15	1.301	1.266	0	75	162	160	37.3	18.2	0	44	100	93

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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U. S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
Public Health Service
Washington 25, D.C.

FOR IMMEDIATE RELEASE
Thursday, August 20, 1959 HEW-L6

The Public Health Service reported today on the levels of radioactivity in milk collected during May and June from twelve sampling stations across the country.

Both the monthly levels and the longer-term averages for all radioactive isotopes analyzed in the milk samples from all stations remained below the levels which the National Committee on Radiation Protection and Measurements considers permissible for life-time exposure by the general population.

The strontium 90 count in milk samples from the St. Louis area dropped from a high of 37.3 micromicrocuries per liter in April to 34.6 micromicrocuries per liter in May and to 11.2 in June.

The maximum concentration of strontium 90 recommended by the National Committee on Radiation Protection and Measurements as permissible for lifetime exposure of the general population is 80 micromicrocuries per liter.

This level, the Public Health Service noted, may be exceeded by varying amounts and for varying periods without causing appreciable harm to the individual.

The milk sampling network is part of the Service's program of measurement of radioactivity in air, water, and food. Milk was chosen for study of

(More)

specific isotopes in foods because it is the most practical to sample and is produced throughout the year in all sections of the country.

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NOTE TO CORRESPONDENTS:

Complete data for May and June together with average levels for all stations are shown on the attached tables. For stations which have been in operation for a year or more, the averages are for the 12-month periods ending with May and June 1959 respectively. For the other stations, the averages are for the periods, through May and June, in which the stations have been in operation.

U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
Public Health Service

Table 1

Analysis Summary of Samples Collected
in May 1959 From Milksheds Serving Specified Areas
(Micromicrocuries per liter)

Area	Iodine 131	Strontium 89	Strontium 90	Barium 140	Cesium 137
Permissible Limits* Lifetime Average Exposure (NCRP&A)	3,000*	7,000*	80.0*	200,000*	150,000*
Atlanta, Ga.	4	94	22.8	0	143
Austin, Texas	11	38	6.5	0	59
Chicago, Ill.	0	57	12.5	0	67
Cincinnati, Ohio	4	53	18.2	0	89
Fargo, N. Dak.-Moorhead, Minn.	1	20	16.2	0	71
New York, N.Y.	0	20	12.0	0	76
Overton, Nevada	0	3	3.8	0	35
Sacramento, Calif.	0	25	8.6	0	65
Salt Lake City, Utah	7	32	9.8	0	60
Spokane, Washington	18	90	22.6	0	104
St. George, Utah	1	15	5.7	0	40
St. Louis, Mo.	0	140	34.6	0	166

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being applicable to milk.

U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
Public Health Service

Table 2

Milk Samples
Average Levels for Period Ending May 1959
(Micromicrocuries per liter)

Area	No. Mos.	Iodine 131	Strontium 89	Strontium 90	Barium 140	Cesium 137
Permissible Limits* Lifetime Average Exposure (NCRP&M)		3,000*	7,000*	80.0*	200,000*	150,000*
Atlanta, Ga.	12	16	70	13.1	9	95
Austin, Texas	12	28	39	4.9	6	50
Chicago, Ill.	11	26	39	7.6	7	71
Cincinnati, Ohio	12	32	71	12.2	23	69
Fargo, N. Dak.-Moorhead, Minn.	12	27	62	13.3	15	83
New York, N.Y.	12	22	38	7.9	14	66
Overton, Nev.	3	0	5	3.7	0	32
Sacramento, Calif.	12	31	24	5.4	3	55
Salt Lake City, U.	12	26	23	5.3	7	42
Spokane, Wash.	10	22	36	10.4	9	79
St. George, Utah	3	1	8	5.8	0	35
St. Louis, Mo.	12	75	163	20.3	43	99

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being applicable to milk.

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

Table 3

Analysis Summary of Samples Collected
in June 1959 From Milksheds Serving Specified Areas
(Micromicrocuries per liter)

Area	Iodine 131	Strontium 89	Strontium 90	Barium 140	Cesium 137
Permissible Limits* Lifetime Average Exposure (NCRP&M)	3,000*	7.000*	80.0*	200,000*	150,000*
Atlanta, Ga.	16	42	19.9	0	105
Austin, Texas	1	24	8.2	0	78
Chicago, Ill.	2	19	12.1	0	76
Cincinnati, Ohio	2	32	17.4	0	56
Fargo, N. Dak.-Moorhead, Minn.	6	44	20.6	0	90
New York, N.Y.	0	28	14.0	0	65
Overton, Nevada	4	4	4.2	0	36
Sacramento, Calif.	3	10	6.4	0	60
Salt Lake City, Utah	7	24	11.8	0	70
Spokane, Washington	5	54	22.1	0	98
St. George, Utah	5	20	7.9	0	65
St. Louis, Mo.	5	77	11.2	0	104

* These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the curren recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being applicable to milk.

U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
Public Health Service

Table 4

Milk Samples
Average Levels for Period Ending June 1959
(Micromicrocuries per liter)

Area	No. Mos.	Iodine 131	Strontium 89	Strontium 90	Barium 140	Cesium 137
Permissible Limits* Lifetime Average Exposure (NCRP&M)		3,000*	7,000*	80.0*	200,000*	150,000*
Atlanta. Ga.	12	17	71	13.6	8	94
Austin, Texas	12	28	39	5.4	6	51
Chicago. Ill.	12	24	37	8.0	6	72
Cincinnati. Ohio	12	32	65	12.7	20	67
Fargo, N.Dak.- Moorhead, Minn.	12	24	59	13.7	13	81
New York, N.Y.	12	22	35	8.2	13	66
Overton, Nevada	4	1	4	3.8	0	33
Sacramento, Calif.	12	11	21	5.3	2	53
Salt Lake City, Utah	12	27	20	5.6	5	42
Spokane. Washington	11	20	38	11.4	8	80
St. George. Utah	4	2	11	6.3	0	42
St. Louis. Mo.	12	75	159	20.0	39	99

* These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being applicable to milk.

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DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

Radioactivity in Milk

Results of Composite Samples from Atlanta, Georgia, Milkshed
for period ending May, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
6-2-58	1.164		0		37		13.7		6		118	
7-2	1.158		22		39		10.2		12		111	
8-2	1.188		65		114		11.9		50		103	
9-2	1.154		20		72		13.8		7		79	
10-2	1.220		6		76		10.4		4		77	
11-2	1.193		32		30		8.8		8		56	
12-3	1.214		21		27		10.2		8		72	
1-7-59	1.242		7		62		13.4		8		84	
2-3	1.218		5		62		7.3		0		80	
3-3	1.246		4		100		14.0		0		98	
4-7	1.181		3		131		20.8		0		114	
5-5	1.265	1.204	4	16	94	70	22.8	13.1	0	9	143	95

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

Radioactivity in Milk

Results of Composite Samples from AUSTIN, TEXAS, Milkshed
for period ending May, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
6-6-58	1.115		0		26		2.2		1		74	
7-3	1.144		8		15		3.5		5		48	
8-6	1.160		50		40		3.4		18		51	
9-4	1.121		16		32		3.9		6		43	
10-3	1.148		11		35		5.1		0		33	
11-5	1.172		181		49		3.7		30		42	
12-3	1.176		39		32		2.6		12		44	
1-6-59	1.216		6		27		5.7		2		39	
2-5	1.153		10		37		6.3		3		49	
3-4	1.169		2		68		7.3		0		62	
4-7	1.158		0		67		8.9		0		60	
5-7	1.179	1.159	11	28	38	39	6.5	4.9	0	6	59	50

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 90	80 " "

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Radioactivity in Milk

Results of Composite Samples from CHICAGO, ILLINOIS, Milkshed
for period ending May, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average
7-16-58	1.069		124		58		7.1		36		112	
8-18	1.098		43		64		9.3		18		88	
9-16	1.161		13		94		7.9		10		71	
10-14	1.123		20		53		6.0		1		55	
11-19	1.141		56		64		8.4		3		64	
12-17	1.103		8		14		7.0		8		71	
1-14-59	1.131		4		6		6.7		0		64	
2-16	1.119		8		1		6.3		0		71	
3-17	1.085		5		6		5.5		0		59	
4-10	1.143		3		7		7.2		0		64	
5-19	1.128	1.118	0	26	57	39	12.5	7.6	0	7	67	71

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from CINCINNATI, OHIO, Milkshed
for period ending May, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
6-16-58	1.227	1.164	0	89	106	50	11.6	6.2	36	33	78	51
7-20	1.082	1.159	107	91	194	62	13.0	6.8	112	40	96	54
8-13	1.102	1.155	42	76	97	63	7.5	7.1	84	39	84	58
9-19	1.132	1.153	5	40	98	65	9.4	7.4	13	29	59	58
10-16	1.175	1.149	31	18	56	59	0.6	7.5	8	24	53	59
11-14	1.157	1.146	177	33	108	64	15.2	8.2	10	24	64	61
12-22	1.148	1.145	8	33	37	66	9.6	8.5	4	24	63	63
1-15-59	1.141	1.142	2	33	33	68	11.7	9.1	4	24	55	64
2-26	1.155	1.142	4	34	14	69	12.2	9.8	0	24	60	64
3-18	1.150	1.148	1	34	19	70	12.9	10.6	0	24	61	64
4-15	1.173	1.150	1	32	39	73	16.5	11.4	0	24	63	66
5-19	1.150	1.149	4	32	53	71	18.2	12.2	0	23	89	69

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000	"	"	
Strontium - 90	80	"	"	
Cesium - 137	150,000	"	"	

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Radioactivity in Milk

Results of Composite Samples from FARGO, N.D.--Moorhead, Minn., Milkshed
for period ending May, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
6-7-58	1.112		30		80		15.6		18		110	
7-6	1.108		92		142		16.3		47		147	
8-3	1.116		48		53		10.2		14		96	
9-4	1.125		27		140		14.1		53		113	
10-1	1.215		20		161		15.0		16		67	
10-30	1.166		86		53		11.5		28		56	
12-4	1.165		0		31		12.3		0		77	
12-31	1.159		2		27		12.3		1		67	
2-4-59	1.135		8		17		11.8		0		61	
3-9	1.109		5		12		12.2		0		67	
4-7	1.163		0		10		12.3		0		61	
5-15	1.136	1.142	1	27	20	62	16.2	13.3	0	15	71	83

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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Radioactivity in Milk

Results of Composite Samples from NEW YORK, N.Y., Milkshed
for period ending May, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
6-17-58	1.093	1.076	0	71	63	39	9.9	5.7	20	36	71	46
7-15	1.062	1.078	67	71	84	43	10.5	5.9	64	39	83	51
8-15	1.048	1.079	69	72	41	40	3.3	5.6	28	35	67	53
9-15	1.241	1.096	10	48	73	39	5.6	5.6	15	25	76	53
10-15	1.141	1.098	61	32	85	36	9.5	5.9	14	13	53	54
11-15	1.089	1.097	35	27	55	38	8.8	6.2	30	15	67	56
12-15	1.114	1.097	9	28	11	37	7.9	6.5	0	15	71	58
1-16-59	1.060	1.092	0	28	10	37	6.9	6.6	3	16	65	61
2-16	1.115	1.094	5	28	6	37	6.5	6.7	0	15	59	62
3-16	1.106	1.099	0	28	5	38	6.5	6.9	0	15	55	63
4-15	1.109	1.101	3	24	7	39	7.6	7.2	0	15	52	63
5-18	1.147	1.110	0	22	20	38	12.0	7.9	0	14	76	66

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000	"	"									
Strontium - 90	80	"	"									

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Radioactivity in Milk

Results of Composite Samples from OVERTON, NEVADA, Milkshed
for period ending May, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
							AVAILABLE TO DATE					
3-15-59	1.098		1		7		4.2		0		31	
4-13	1.094		0		4		3.1		0		30	
5-12	1.091		0		3		3.8		0		35	

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from SACRAMENTO, CALIFORNIA, Milkshed
for period ending May, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
6-15-58	1.122	1.133	240	26	40	24	7.1	4.8	6	18	79	58
7-13	1.036	1.128	45	28	20	24	3.3	4.9	7	18	53	56
8-17	1.150	1.131	22	29	24	24	6.8	5.3	0	17	65	55
9-17	1.161	1.137	9	29	17	24	3.8	5.5	0	15	72	57
10-14	1.109	1.134	12	28	11	23	1.4	5.4	1	11	39	57
11-18	1.111	1.131	17	30	18	24	6.1	5.1	14	8	46	57
12-14	1.166	1.132	14	31	10	25	4.2	5.1	6	7	48	58
1-15-59	1.150	1.131	0	31	15	24	4.3	5.0	0	7	35	57
2-23	1.151	1.133	3	31	12	25	3.9	5.0	0	6	46	57
3-15	1.133	1.131	1	31	58	28	7.7	5.2	0	6	60	58
4-19	1.148	1.132	4	31	36	25	7.5	5.0	0	4	50	54
5-16	1.147	1.132	0	31	25	24	8.6	5.4	0	3	65	55

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000 " "
Strontium - 90	80 " "

Cesium - 137	150,000 " "

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Public Health Service

Radioactivity in Milk

Results of Composite Samples from SALT LAKE CITY, UTAH, Milkshed
for period ending May, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
6-11-58	1.129	1.140	0	186	68	33	7.3	4.2	21	41	59	60
7-15	1.068	1.136	156	184	26	33	4.7	4.2	16	26	40	59
8-14	1.108	1.135	77	174	44	31	4.2	4.2	20	24	43	59
9-13	1.207	1.142	14	113	44	30	5.0	4.2	14	18	48	51
10-13	1.187	1.143	11	32	26	24	3.1	4.0	5	8	31	49
11-14	1.162	1.142	33	34	13	23	5.2	4.1	4	8	37	49
12-16	1.161	1.142	8	31	5	23	6.1	4.3	0	7	39	49
1-15-59	1.137	1.140	2	31	6	23	4.5	4.4	5	8	34	49
2-17	1.176	1.147	1	28	5	22	3.4	4.5	0	8	37	46
3-16	1.176	1.149	2	28	4	22	4.6	4.7	0	8	38	43
4-15	1.118	1.148	5	26	6	23	5.4	4.7	0	8	32	40
5-14	1.132	1.147	7	26	32	23	9.8	5.3	0	7	60	42

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from SPOKANE, WASHINGTON, Milkshed
for period ending May, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	10 Mo. Average	Sample	10 Mo. Average	Sample	10 Mo. Average	Sample	10 Mo. Average	Sample	10 Mo. Average	Sample	10 Mo. Average
8-8-58	1.168		68		64		6.9		18		93	
9-3	1.163		11		43		8.2		5		78	
10-2	1.202		8		53		8.6		8		72	
11-6	1.223		67		35		11.9		52		72	
11-30	1.241		30		21		8.6		7		84	
1-2-59	1.268		7		20		9.1		3		73	
2-3	1.183		4		16		6.3		0		84	
3-2	1.236		8		6		10.9		0		68	
4-6	1.172		0		15		10.5		0		58	
5-5	1.164	1.202	18	22	90	36	22.6	10.4	0	9	104	79

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from ST. GEORGE, UTAH, Milkshed
for period ending May, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
3-20-59	1.161		3		2		6.0		0		33	
4-11	1.104		0		6		5.6		0		32	
5-13	1.125		1		15		5.7		0		40	

AVAILABLE TO DATE

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from ST. LOUIS, MO., Milkshed
for period ending May, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
6-18-58	1.217	1.258	0	197	122	74	14.8	9.6	44	83	96	59
7-16	1.175	1.257	624	233	306	99	18.7	10.2	229	90	160	67
8-19	1.280	1.264	61	220	263	115	14.1	10.7	113	95	109	73
9-16	1.303	1.272	19	141	283	118	15.4	11.2	48	55	104	76
10-16	1.271	1.272	35	70	138	118	12.2	11.4	14	46	71	77
11-18	1.280	1.270	123	80	168	126	20.1	12.5	36	48	74	80
12-16	1.274	1.267	23	82	84	130	15.6	13.2	8	48	75	82
1-17-59	1.329	1.268	7	83	77	134	18.6	14.1	14	48	64	84
2-17	1.282	1.266	0	83	84	140	19.6	15.1	4	48	73	86
3-16	1.225	1.262	4	83	130	150	22.5	16.2	5	48	92	89
4-15	1.301	1.266	0	75	162	160	37.3	18.2	0	44	100	93
5-19	1.234	1.264	0	75	140	163	34.6	20.3	0	43	166	99

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from Atlanta, Georgia, Milkshed
for period ending June, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
7-2-58	1.158		22		39		10.2		12		111	
8-2	1.188		65		114		11.9		50		103	
9-2	1.154		20		72		13.8		7		79	
10-2	1.220		6		76		10.4		4		77	
11-2	1.193		32		30		8.8		8		56	
12-3	1.214		21		27		10.2		8		72	
1-7-59	1.242		7		62		13.4		8		84	
2-3	1.218		5		62		7.3		0		80	
3-3	1.246		4		100		14.0		0		98	
4-7	1.181		5		131		20.8		0		114	
5-5	1.265		4		94		22.8		0		143	
6-11	1.249	1.211	16	17	42	71	19.9	13.6	0	8	105	94

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from AUSTIN, TEXAS, Milkshed
for period ending June, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
7-3-58	1.144		8		15		3.5		5		48	
8-6	1.160		50		40		3.4		18		51	
9-4	1.121		16		32		3.9		6		43	
10-3	1.148		11		35		5.1		0		33	
11-5	1.172		181		49		3.7		30		42	
12-3	1.176		39		32		2.6		12		44	
1-6-59	1.216		6		27		5.7		2		39	
2-5	1.153		10		37		6.3		3		49	
3-4	1.169		2		68		7.3		0		62	
4-7	1.158		0		67		8.9		0		60	
5-7	1.179		11		38		6.5		0		59	
6-5	1.123	1.160	1	28	24	39	8.2	5.4	0	6	78	51

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from CHICAGO, ILLINOIS, Milkshed
for period ending June, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average
8-18-58	1.098		43		64		9.3		18		88	
9-16	1.161		13		94		7.9		10		71	
10-14	1.123		20		53		6.0		1		55	
11-19	1.141		56		64		8.4		3		64	
12-17	1.103		8		14		7.0		8		71	
1-14-59	1.131		4		6		6.7		0		64	
2-16	1.119		8		1		6.3		0		71	
3-17	1.085		5		6		5.5		0		59	
4-10	1.143		3		7		7.2		0		64	
5-19	1.128		0		57		12.5		0		67	
6-17	1.164	1.122	2	24	19	37	12.1	8.0	0	6	76	72

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from CINCINNATI, OHIO, Milkshed
for period ending June, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
7-20-58	1.082	1.159	107	91	194	62	13.0	6.8	112	40	96	54
8-13	1.102	1.155	42	76	97	63	7.5	7.1	84	39	84	58
9-19	1.132	1.153	5	40	98	65	9.4	7.4	13	29	59	58
10-16	1.175	1.149	31	18	56	59	8.6	7.5	8	24	53	59
11-14	1.157	1.146	177	33	108	64	15.2	8.2	10	24	64	61
12-22	1.148	1.145	8	33	37	66	9.6	8.5	4	24	63	63
1-15-59	1.141	1.142	2	33	33	68	11.7	9.1	4	24	55	64
2-26	1.155	1.142	4	34	14	69	12.2	9.8	0	24	60	64
3-18	1.150	1.148	1	34	19	70	12.9	10.6	0	24	61	64
4-15	1.173	1.150	1	32	39	73	16.5	11.4	0	24	63	66
5-19	1.150	1.149	4	32	53	71	18.2	12.2	0	23	89	69
6-16	1.151	1.143	2	32	32	65	17.4	12.7	0	20	56	67

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000	"	"					Cesium - 137	150,000	"	"	
Strontium - 90	80	"	"									

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Radioactivity in Milk

Results of Composite Samples from FARGO, N.D.--Moorhead, Minn., Milkshed
for period ending June, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
7-6-58	1.108		92		142		16.3		47		147	
8-3	1.116		48		53		10.2		14		96	
9-4	1.125		27		140		14.1		53		113	
10-1	1.215		20		161		15.0		16		67	
10-30	1.166		86		53		11.5		28		56	
12-4	1.165		0		31		12.3		0		77	
12-31	1.159		2		27		12.3		1		67	
2-4-59	1.135		8		17		11.8		0		61	
3-9	1.109		5		12		12.2		0		67	
4-7	1.163		0		10		12.3		0		61	
5-15	1.136		1		20		16.2		0		71	
6-12	1.153	1.146	6	24	44	59	20.6	13.7	0	13	90	81

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Radioactivity in Milk

Results of Composite Samples from NEW YORK, N.Y., Milkshed
for period ending June, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
7-15-58	1.062	1.078	67	71	84	43	10.5	5.9	64	39	83	51
8-15	1.048	1.079	69	72	41	40	3.3	5.6	28	35	67	53
9-15	1.241	1.096	10	48	73	39	5.6	5.6	15	25	76	55
10-15	1.141	1.098	61	52	85	36	9.5	5.9	14	13	53	54
11-15	1.089	1.097	35	27	55	38	8.8	6.2	30	15	67	56
12-15	1.114	1.097	9	28	11	37	7.9	6.5	0	15	71	58
1-16-59	1.060	1.092	0	28	10	37	6.9	6.6	3	16	65	61
2-16	1.115	1.094	5	28	6	37	6.5	6.7	0	15	59	62
3-16	1.106	1.099	0	28	5	38	6.5	6.9	0	15	55	63
4-15	1.109	1.101	3	24	7	39	7.6	7.2	0	15	52	63
5-18	1.147	1.110	0	22	20	38	12.0	7.9	0	14	76	66
6-15	1.136	1.114	0	22	28	35	14.0	8.2	0	13	65	66

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000	"	"	
Strontium - 90	80	"	"	
Cesium - 137	150,000	"	"	

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Radioactivity in Milk

Results of Composite Samples from OVERTON, NEVADA, Milkshed
for period ending June, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	4 Mo. Average	Sample	4 Mo. Average	Sample	4 Mo. Average	Sample	4 Mo. Average	Sample	4 Mo. Average	Sample	4 Mo. Average
							AVAILABLE TO DATE					
3-15-59	1.098		1		7		4.2		0		31	
4-13	1.094		0		4		3.1		0		30	
5-12	1.091		0		3		3.8		0		35	
6-14	1.055	1.084	4	1	4	4	4.2	3.8	0	0	36	33

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

Radioactivity in Milk

Results of Composite Samples from SACRAMENTO, CALIFORNIA, Milkshed
for period ending June, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
7-13-58	1.036	1.128	45	28	20	24	3.3	4.9	7	18	53	56
8-17	1.150	1.131	22	29	24	24	6.8	5.3	0	17	65	55
9-17	1.161	1.137	9	29	17	24	3.8	5.5	0	15	72	57
10-14	1.109	1.134	12	28	11	23	1.4	5.4	1	11	39	57
11-18	1.111	1.131	17	30	18	24	6.1	5.1	14	8	46	57
12-14	1.166	1.132	14	31	10	25	4.2	5.1	6	7	48	58
1-15-59	1.150	1.131	0	31	15	24	4.3	5.0	0	7	35	57
2-25	1.151	1.133	3	31	12	25	3.9	5.0	0	6	46	57
3-15	1.133	1.131	1	31	58	28	7.7	5.2	0	6	60	58
4-19	1.148	1.132	4	31	36	25	7.5	5.0	0	4	50	54
5-16	1.147	1.132	0	31	25	24	8.6	5.4	0	3	65	55
6-15	1.157	1.133	3	11	10	21	6.4	5.3	0	2	60	53

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000 " "	Cesium - 137	150,000 " "	
Strontium - 90	80 " "			

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Public Health Service

Radioactivity in Milk

Results of Composite Samples from SALT LAKE CITY, UTAH, Milkshed
for period ending June, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
7-15-58	1.068	1.136	156	184	26	33	4.7	4.2	16	26	40	59
8-14	1.108	1.135	77	174	44	31	4.2	4.2	20	24	43	59
9-13	1.207	1.142	14	113	44	30	5.0	4.2	14	18	48	51
10-13	1.187	1.143	11	32	26	24	3.1	4.0	5	8	31	49
11-14	1.162	1.142	33	34	13	23	5.2	4.1	4	8	37	49
12-16	1.161	1.142	8	31	5	23	6.1	4.3	0	7	39	49
1-15-59	1.137	1.140	2	31	6	23	4.5	4.4	5	8	34	49
2-17	1.176	1.147	1	28	5	22	3.4	4.5	0	8	37	46
3-16	1.176	1.149	2	28	4	22	4.6	4.7	0	8	38	43
4-15	1.118	1.148	5	26	6	23	5.4	4.7	0	8	32	40
5-14	1.132	1.147	7	26	32	23	9.8	5.3	0	7	60	42
6-15	1.123	1.146	7	27	24	20	11.8	5.6	0	5	70	42

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

Radioactivity in Milk

Results of Composite Samples from SPOKANE, WASHINGTON, Milkshed
for period ending June, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average	Sample	11 Mo. Average
8-8-58	1.168		68		64		6.9		18		93	
9-3	1.163		11		43		8.2		5		78	
10-2	1.202		8		53		8.6		8		72	
11-6	1.223		67		35		11.9		52		72	
11-30	1.241		30		21		8.6		7		84	
1-2-59	1.268		7		20		9.1		3		73	
2-3	1.183		4		16		6.3		0		84	
3-2	1.236		8		6		10.9		0		68	
4-6	1.172		0		15		10.5		0		58	
5-5	1.164		18		90		22.6		0		104	
6-1	1.162	1.198	5	20	54	38	22.1	11.4	0	8	98	80

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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Strontium - 89	7,000	"	"			
Strontium - 90	80	"	"			

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Public Health Service

Radioactivity in Milk

Results of Composite Samples from ST. GEORGE, UTAH, Milkshed
for period ending June, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	4 Mo. Average	Sample	4 Mo. Average	Sample	4 Mo. Average	Sample	4 Mo. Average	Sample	4 Mo. Average	Sample	4 Mo. Average
3-20-59	1.161		3		2		6.0		0		33	
4-11	1.104		0		6		5.6		0		32	
5-13	1.125		1		15		5.7		0		40	
6-12	1.137	1.132	5	2	20	11	7.9	6.3	0	0	65	42

AVAILABLE TO DATE

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

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DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service

Radioactivity in Milk

Results of Composite Samples from ST. LOUIS, MO., Milkshed
for period ending June, 1959

Date of collection	Calcium Content grams/liter		Radioactivity in uuc/liter*									
			Iodine - 131		Strontium - 89		Strontium - 90		Barium - 140		Cesium - 137	
	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average	Sample	12 Mo. Average
7-16-58	1.175	1.257	624	233	306	99	18.7	10.2	229	90	160	67
8-19	1.280	1.264	61	220	263	115	14.1	10.7	113	95	109	73
9-16	1.303	1.272	19	141	283	118	15.4	11.2	48	55	104	76
10-16	1.271	1.272	35	70	138	118	12.2	11.4	14	46	71	77
11-18	1.280	1.270	123	80	168	126	20.1	12.5	36	48	74	80
12-16	1.274	1.267	23	82	84	130	15.6	13.2	8	48	75	82
1-17-59	1.329	1.268	7	83	77	134	18.6	14.1	14	48	64	84
2-17	1.282	1.266	0	83	84	140	19.6	15.1	4	48	73	86
3-16	1.225	1.262	4	83	130	150	22.5	16.2	5	48	92	89
4-15	1.301	1.266	0	75	162	160	37.3	18.2	0	44	100	93
5-19	1.234	1.264	0	75	140	163	34.6	20.3	0	43	166	99
6-17	1.277	1.269	5	75	77	159	11.2	20.0	0	39	104	99

*These limits are the maxima permissible limits for lifetime exposure of population groups to specific radioisotopes in water and are derived from the current recommendations of the National Committee on Radiation Protection and Measurements. The limits have been generally accepted as being equally applicable to milk.

Iodine - 131	3,000 uuc/liter	Barium - 140	200,000 uuc/liter
Strontium - 89	7,000 " "	Cesium - 137	150,000 " "
Strontium - 90	80 " "		

Appendix F

AGENDA

RADIOLOGICAL HEALTH CONFERENCE

PUBLIC HEALTH SERVICE
ASSOCIATION OF STATE AND TERRITORIAL HEALTH OFFICERS
ATOMIC ENERGY COMMISSION

Cosmopolitan Hotel
Denver, Colorado

April 13 and 14, 1959

(All Meeting Rooms are located on the Mezzanine Floor, Cosmopolitan Hotel)

April 13, 1959

8:15 A.M. - 9:45 A.M. - Century Room

Registration

9:00 A.M. - Century Room

General Introduction and Statement of Purposes of the Conference	- Dr. Leroy E. Burney Surgeon General, PHS
Welcome	- Dr. Albert H. Rosenthal Regional Director, DHEW Region VIII

Federal-State Relations:

Chairman: Dr. Mack I. Shanholtz, Secretary-Treasurer of the Association of State and Territorial Health Officers

1. Public Health Service Interests	- Dr. Francis J. Weber, Chief Division of Radiological Health, PHS
2. Federal-State Relations in the Control of Atomic Energy Materials	- Mr. Harold Price, Director Division of Licensing and Regulation Atomic Energy Commission
3. The State Viewpoint	- Dr. Mack I. Shanholtz State Health Commissioner Virginia Department of Health
	- Dr. R. L. Cleere, Executive Director Colorado State Department of Public Health

12:30 Noon - Luncheon - Club Room

The Emerging Problems in Radiological Health	- Dr. Leroy E. Burney Surgeon General, PHS

2:00 P.M. - Century Room

Chairman: Dr. Theodore J. Bauer, Deputy Chief, Bureau of State Services, PHS

Trends in Radiation Exposure	- Mr. James G. Terrill, Jr. Ass't. Chief, Division of Radiological Health, PHS
State of Knowledge in Terms of Medical X-ray Protection	- Dr. Richard H. Chamberlain, Member National Advisory Committee on Radiati
Research in Radiation Control Programs	- Dr. Russell H. Morgan, Chairman National Advisory Committee on Radiati
Statutory Obligations of Food and Drug Administration in Relation to Radioactive Contamination of Food	- Mr. W. B. Rankin, Assistant to the Commissioner Food and Drug Administration

April 13, 1959 (cont'd)

Problems in Research Related to the Development of Standards for Radiation Protection	- Dr. Charles L. Dunham, Director Division of Biology and Medicine, AEC
Summary of Existing Facilities for Radiological Health Training	- Dr. Arthur H. Wolff, Chief Training Branch Division of Radiological Health, PHS

5:30 P.M. - 6:30 P.M. - Social Hour - American Legion Building, 14th and Broadway

April 14, 1959

9:30 A.M.

Round-table Discussions (Choice to be indicated at time of registration)

	Chairmen:
1. Radiological Health Training (Century Room)	- Dr. R. N. Barr Secretary and Executive Officer Minnesota Department of Health
2. Research and Laboratory Services (Derrick Room)	- Dr. Malcolm H. Merrill Director of Public Health California Department of Public Health
3. Technical and Consultant Services Including Loan of Personnel (Branding Iron Room)	- Dr. Harold M. Erickson State Health Officer Oregon State Board of Health
4. Legislative and Regulatory Aspects (Governor's Room)	- Dr. Henry A. Holle Commissioner of Health Texas State Department of Health
5. State Program Development and Needs (Director's Room)	- Dr. Ralph E. Dyer Director of Health Ohio Department of Health

NOTE: It is suggested that each Chairman designate a Recorder for his discussion group. Resource persons will be selected from the Division of Radiological Health staff and certain others attending the Conference.

April 14, 1959 (cont'd)

1:30 P.M. - 4:00 P.M. - Century Room

Chairman: Dr. Andrew C. Offutt, Secretary of State Board of Health and State Health Commissioner, Indiana Board of Health

Reports from the discussion groups and discussion of these reports.

COFFEE BREAKS DAILY AT APPROXIMATELY 10:30 A.M. and 3:00 P.M.

Representative HOLIFIELD. The next witness is Mr. Joshua Holland, Division of Biology and Medicine, AEC.

STATEMENT OF JOSHUA HOLLAND,[1] DIVISION OF BIOLOGY AND MEDICINE, ATOMIC ENERGY COMMISSION

Mr. HOLLAND. Thank you, Mr. Chairman.

Mr. Chairman and gentlemen, in the short time available, I shall attempt to give a broad brush picture of the findings on fallout which are emerging from the large mass of data collected during the past 2 years. This is intended to provide a frame of reference for the discussions which are to follow and will be limited to averages, extremes, and illustrative examples without interpretation as to models, mechanisms, or effects on people.

For each sampling program a more detailed summary of the data is being submitted for the record by the person most familiar with that particular program. The soil data are being submitted by Dr. Lyle Alexander, of the Department of Agriculture. The rainpot data are being reported by Dr. John Harley, of our Health and Safety Laboratory. The detailed surface-air-filter data are being submitted by Dr. Luther Lockhart, of the Naval Research Laboratory; and the upper-air-filter data by myself. (See p. 575.)

My first chart shows the results of strontium 90 analyses of foreign soils collected throughout the world by Dr. Lyle Alexander during the spring of 1958. The Hawaiian Islands are included in this chart. The level of strontium 90 radioactivity is shown by the vertical axis and the latitude is shown horizontally, with the North Pole on the left, the South Pole on the right, and the Equator in the middle. Each individual sample is shown by a dot, and the average for each 10° latitude zone is shown by a bar. For comparison, the same averages based on the 1956 samples are shown by broken horizontal bars.

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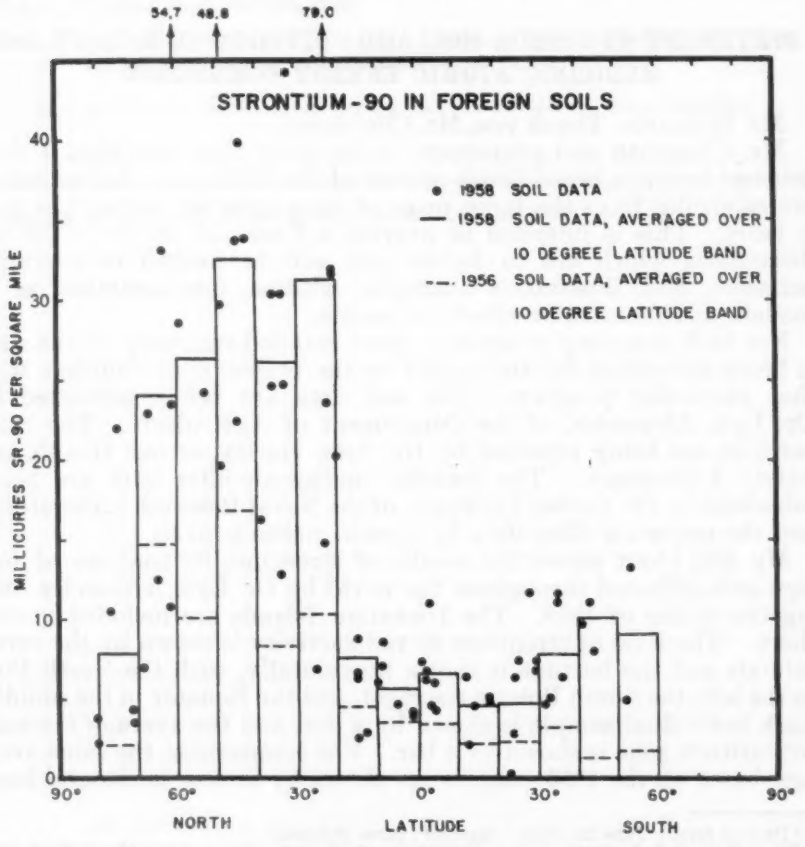
[1] Date of birth: June 23, 1921. Married: three children.
Education: B.S. in mathematics, University of Chicago, 1941. Graduate work at University of Chicago in meteorology, 1941–42. Graduate work in physics and mathematics, University of Tennessee, 1950–52.
Experience: Served as weather officer, second lieutenant to major, U.S. Army Air Forces during World War II. Duties included teaching, research, forecasting, and radar-weather projects. Conducted 5-year research program on air pollution meteorology at AEC Oak Ridge Area as meteorologist in charge, Weather Bureau Office, Oak Ridge, Tenn. Served 2 years as research meteorologist and civil defense coordinator at Weather Bureau Central Office, Washington, working on problems of forest-fire weather, drought, long-range forecasting, hazards of nuclear reactors and fallout. Served 2 years as executive secretary to AEC Advisory Committee on Reactor Safeguards and staff consultant on problems of radioactive contamination of the air due to peaceful uses of atomic energy.
Affiliations: American Meteorological Society, Interdepartmental Committee on Community Air Pollution. Consultant to National Academy of Sciences Committee on Meteorological Aspects of the Effects of Atomic Radiation.
Publications: 18 scientific articles on micrometeorology, turbulence, atmospheric diffusion, air pollution, reactor hazards, circulation of the atmosphere, weather forecasting, gamma radiation, fallout.

(The chart referred to follows:)



Mr. HOLLAND. It is clear that the maximum levels of strontium 90 contamination of soil occur in the zone 40° to 50° north. The average value of about 33 millicuries of strontium 90 per square mile is to be compared with 17 in 1956. This is the latitude band which includes the northern half of the United States and southern Europe.

In the equatorial zone the levels run about 5 millicuries per square mile or about one-sixth of those of the north temperate latitudes. There is then an increase to about 10 in the south temperate latitudes. Generally speaking the 1958 levels are roughly double those measured in 1956.

Representative HOLIFIELD. Would it be safe to say that if weapons are exploded in either the tropical zone or the Arctic zone that the majority of the fallout would be in the Temperate Zone?

Mr. HOLLAND. This appears to be the case.

Representative VAN ZANDT. Mr. Holland, the information you are giving us now, is it strictly U.S. information?

Mr. HOLLAND. This is information collected by U.S. agencies; yes, sir.

Representative VAN ZANDT. Do you draw on the information of friendly countries?

Mr. HOLLAND. We have access to information from friendly countries, particularly unclassified information, but I have not included that here.

Representative VAN ZANDT. The information you receive from friendly countries, is it in addition to information received from the Soviets?

Mr. HOLLAND. We do not receive information of this kind from the Soviets to my knowledge. I think some of the other people here have better information about that through the U.N. Scientific Committee. Mr. Eisenbud, for instance.

Senator BENNETT. If there was any appreciable number of detonations between the Equator and the South Pole or near the South Pole, would that chart fill up on the other side?

Mr. HOLLAND. I think that most of us would expect that it would fill in on the south side.

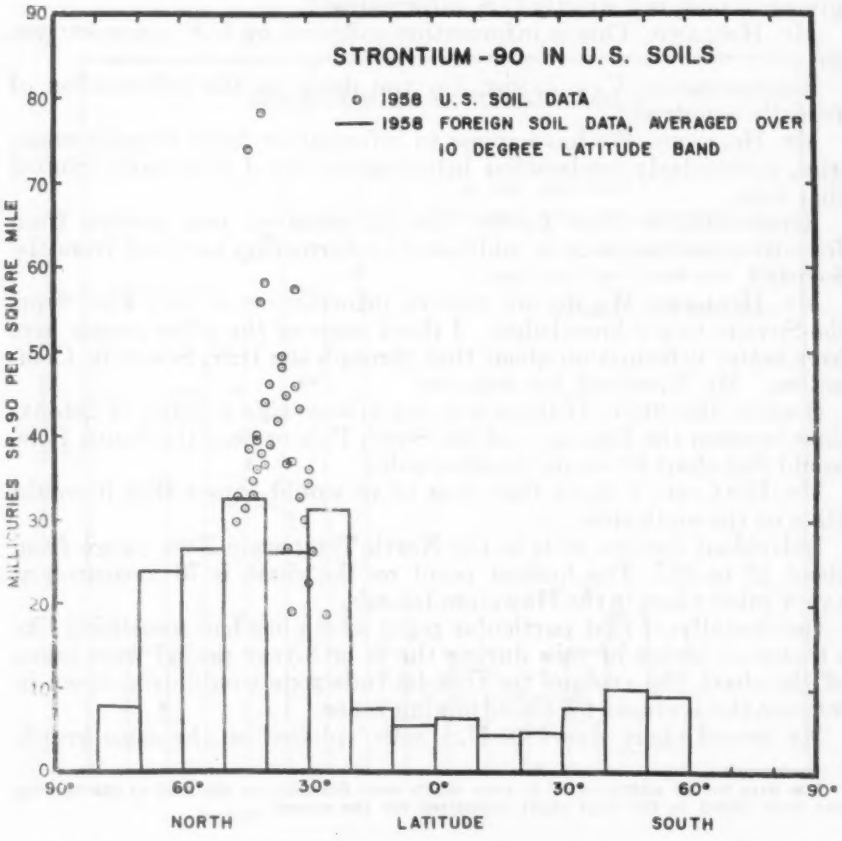
Individual foreign soils in the North Temperate Zone range from about 13 to 39. The highest point on the chart is 79 measured at a very rainy place in the Hawaiian Islands.

Incidentally, if that particular point which has had something like a thousand inches of rain during the 7- or 8-year period were taken off the chart, the average for that latitude zone would drop down in between the averages for the adjoining zones.

My second chart shows 10 U.S. soils [1] plotted on the same graph.

[1] The data for 25 additional U.S. soils which were available at the time of the hearing have been added in the final chart submitted for the record.

(The chart referred to follows:)



Mr. HOLLAND. The horizontal bars are still the average for foreign soils only, as on the previous chart. The U.S. soils appear to be more heavily contaminated with strontium 90 than those in other regions sampled within the same latitude zones.

I should make a qualifying remark here. The U.S. soils were collected in October 1958, and the foreign soils in the spring. So there would be a slight difference in the U.S. soils due to the difference in the sampling time. This we do not think is sufficient to account for the higher U.S. soils.

I want to point out that the number plotted at 84 is incorrect.[2] The five highest soils I can read. Salt Lake City is 78, Rapid City, S. Dak., is 74, Springfield, Ill., is 58, Sanger, Tex., 57, and Des Moines, Iowa, 56. These are the five highest, just for your information. Those are considerably higher than the average for the same latitudes in other countries.

Representative HOLIFIELD. This is expressed in thousandths of a curie per square mile?

[2] This correction has been made in the final chart submitted for the record.

Mr. HOLLAND. These are expressed in thousandths of a curie per square mile. For comparison, when we say 40 megatons of fission have been detonated, this produces something like 4 million curries of strontium 90. So that 4 million curies divided by the area of the earth, which is about 200 million square miles, if deposited evenly would produce 20 millicuries per square mile.

Representative HOLIFIELD. But of course it is not distributed evenly. So therefore you have to take a particular reading on the percentage that is deposited in the Temperate Zone.

Mr. HOLLAND. That is correct.

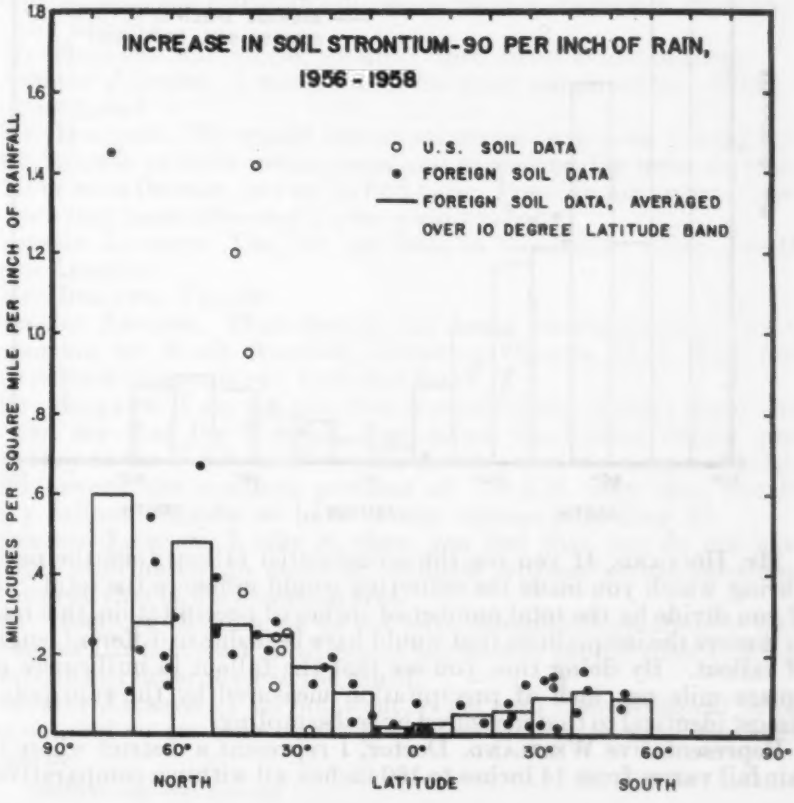
Representative HOLIFIELD. And also between the rainy areas and the dry areas.

Mr. HOLLAND. We use this average as sort of a reference level, although it is a fictitious one, admittedly.

The variation of soil strontium 90 with latitude does not follow closely the variation of rainfall with latitude. However, within each latitude zone the strontium 90 levels in soil do seem to be roughly proportional to the rainfall.

In my next chart, the fallout occurring in the 2 years between the 1956 and 1958 soil samplings has been divided by the total precipitation which fell at each location during this 2-year period. The result is shown in millicuries of strontium 90 per square mile per inch of rainfall.

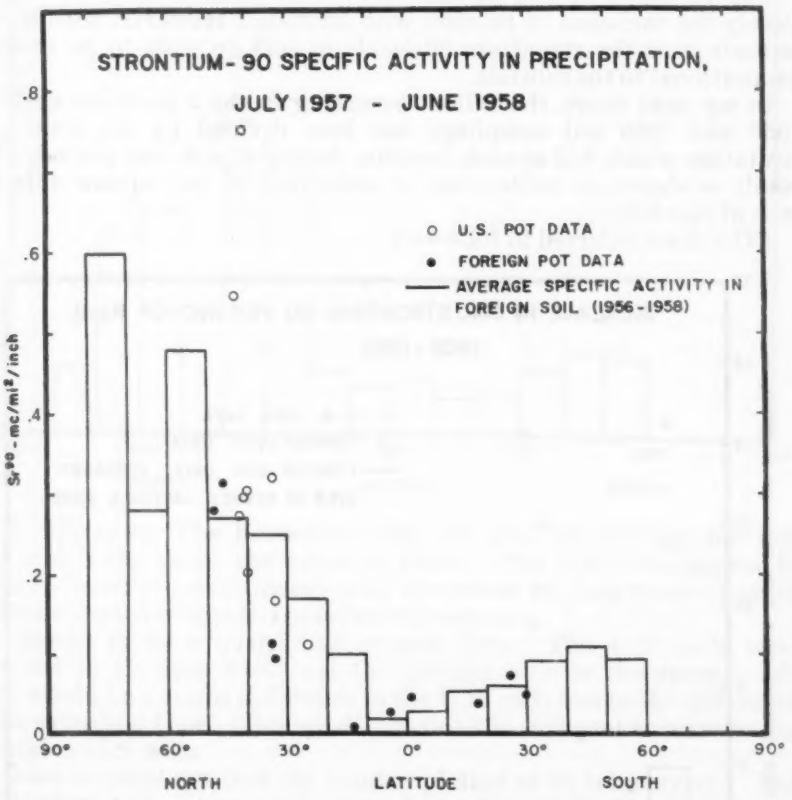
(The chart referred to follows:)



Mr. HOLLAND. It is clear that even allowing for variations in rainfall the north temperate latitudes have the greatest amount of strontium 90 fallout. In fact, because of the high equatorial rainfall and low equatorial fallout, the contrast between the equatorial and the temperate latitudes shows up even more clearly in this type of presentation.

While the soil analyses give the best measure of total accumulated strontium 90 fallout, our best measure of the rate of fallout per month or per year is obtained from our pot collectors. To show how the pot data compare with the soil data, my next chart presents the total milicuries per square mile measured at each pot station during the period July 1957 through June 1958 divided by the number of inches of precipitation during that period.

(The chart referred to follows:)



Mr. HOLLAND. If you use the accumulated fallout then the period during which you made the collection would influence the total. But if you divide by the total number of inches of precipitation, this tends to remove the inequalities that would have been due to different lengths of fallout. By doing this, you see that the fallout in millicuries per square mile per inch of precipitation measured by the rain pots is almost identical to that measured by soil sampling.

Representative WESTLAND. Doctor, I represent a district where the rainfall varies from 14 inches to 160 inches, all within a comparatively

small area. Are you telling me that where we have 160 inches of rainfall that there would be 10 times as much strontium 90 deposited as there would be in the 16 inch annual rainfall area?

Mr. HOLLAND. I think you will find essentially just that. If there are more questions on this, Dr. Alexander is here, and might be willing to answer them. I think he has done precisely this type of sampling in the Hawaiian Islands and has found that the total strontium 90 deposited on a level surface of ground is approximately proportional to the total rainfall within a small area. That is, if the distances are not too great, and you don't get into entirely different climatic regions.

Representative WESTLAND. I am sure the Senator from Washington would be interested in your putting one of these pots, whatever they may be, in such areas as that, if this is a so-called hot area. You would get some pretty definite information.

Mr. HOLLAND. A couple of years ago we did have some measurements made in the State of Washington in very rainy and relatively dry areas, and these contrasts were brought out very clearly.

Senator JACKSON. I want to add that in the Seattle area we have actually less rainfall than we do in Washington, D.C. This town is quite tropical here in the summertime. I just wanted to ask one question, Mr. Chairman.

Doctor, based on the computations that you have made, can you give us a rough comparison of the effect of these tests in NorthAmerica as compared with the Eurasian land mass, namely, European Russia and Asiatic Russia?

Mr. HOLLAND. Of course, we don't have direct evidence there.

Senator JACKSON. I mean based on your computation. What is your estimate?

Mr. HOLLAND. We would expect an excess in a zone roughly the same latitude as their testing sites and extending for some thousand miles or so to the east, just as we find here. Possibly somewhat bigger, because they have detonated higher yield weapons.

Senator JACKSON. Yes, but our tests in the Pacific affect directly North America.

Mr. HOLLAND. Yes, sir.

Senator JACKSON. Their tests in the Arctic have a greater effect in proportion on North America, including Canada, than their tests have in their own country. Isn't that fair?

Mr. HOLLAND. I am not sure this is established. I don't know that we can say that the U.S.S.R. tests affect the United States more than they do the U.S.S.R. It is quite possible that the comparable latitudes toward the southern portions of U.S.S.R. may have equally heavy fallout. Maybe we have rainier regions than they do.

Senator JACKSON. I take it, then, you feel that you do not have enough information to make an estimate without actual samplings in the area, that is, the Eurasian area.

Mr. HOLLAND. I think we do not have enough information to state unequivocally that the United States has heavier fallout from U.S.S.R. tests than any other place in the world.

Senator JACKSON. I do not want to get into meteorological information, and so on, that would give some clue as to what the effect would be.

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Mr. HOLLAND. So far as I know, there is no such evidence that would rule out the possibility that other regions in the same latitudes might have comparable levels of fallout.

Representative HOLIFIELD. You may proceed.

Mr. HOLLAND. The horizontal bars, for comparison, are again the average millicuries per square mile per inch for each latitude zone obtained from the foreign soil data, repeated from the previous chart. These two independent sources of information give essentially the same picture. I have shown the U.S. pot data here as open circles, and the foreign pot data as black spots. You see that the U.S. pot data tend to run somewhat higher than the foreign pots at the same latitude also.

Representative HOLIFIELD. When you refer to the charts, do not depend upon the written record to carry the meaning of the chart unless you announce the difference in terms of degrees there as against the latitude. Then the record will carry it.

Mr. HOLLAND. Yes, sir. The charts, of course, will be reproduced in the record, too.

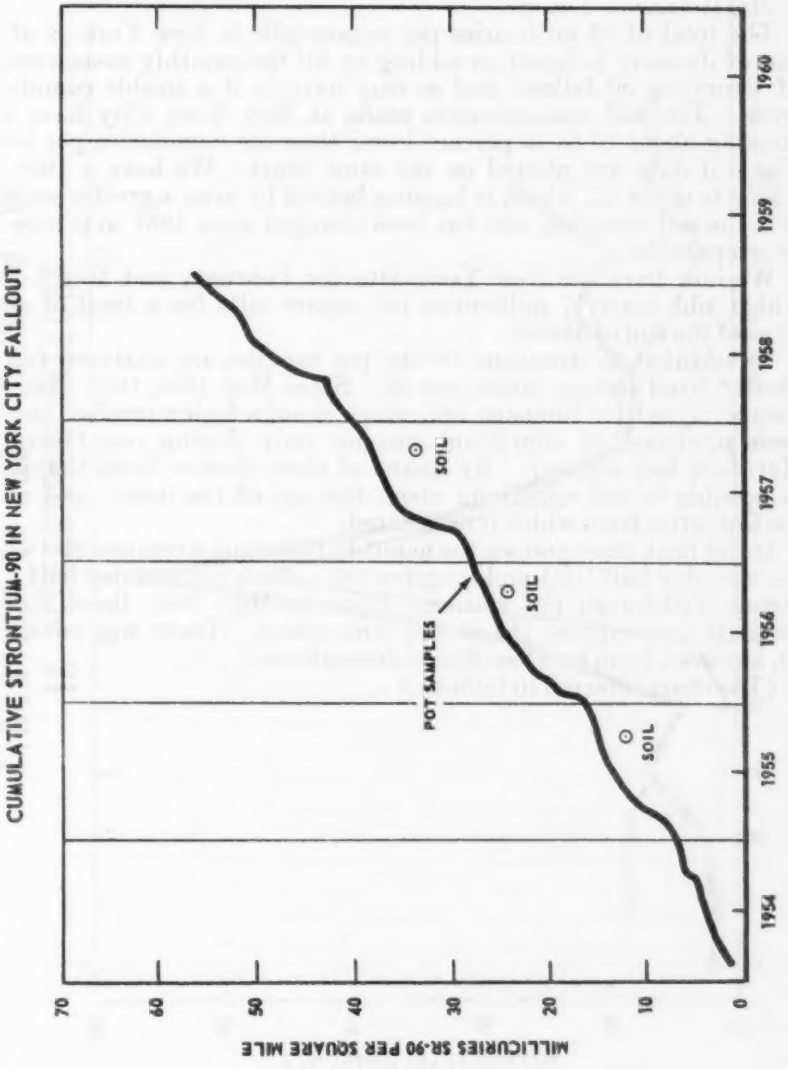
From these fallout measurements we obtain an estimate of 2½ to 3 megacuries—a megacurie is 1 million curies—of strontium 90 for the total deposited on the surface of the earth, excluding the local fallout zones within a few hundred miles of the test sites as of mid-1958. That was 2.5 million to 3 million curies. If you add up the yields in the data that Dr. Dunham distributed this morning, you will find that this is roughly one-third of all of the strontium 90 produced in tests.

The fallout has not been coming down at a uniform rate.

The next chart shows the accumulated fallout at New York City as it has changed with time since 1954, based on rain-pot samples. The buildup has been generally most rapid during the spring and slowest during the fall each year.

CHART 5

(The chart referred to follows:)



Representative HOLIFIELD. Could you please take the microphone in your hand, Doctor. The acoustics in this room are very bad.

Mr. HOLLAND. Yes, sir.

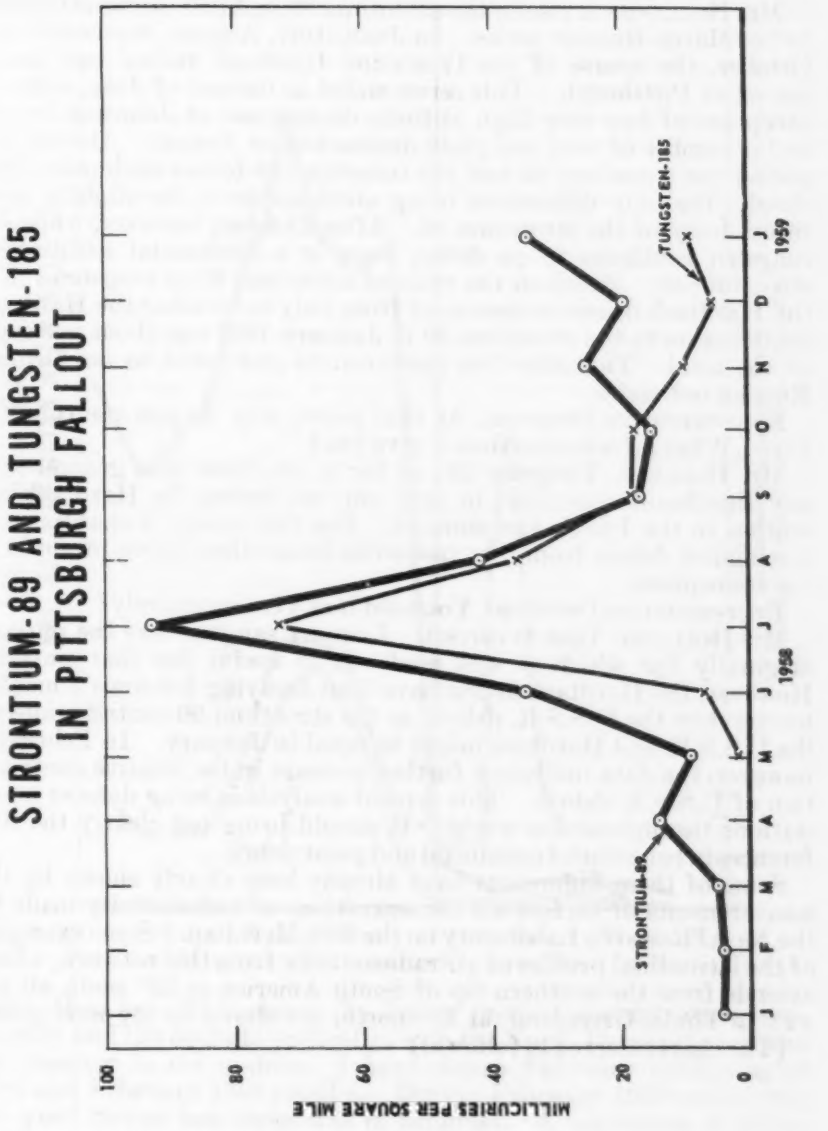
The total of 56 millicuries per square mile in New York as of the end of January is based on adding up all the monthly measurements of strontium 90 fallout, and so may have in it a sizable cumulative error. The soil measurements made at New York City have been running about 10 to 15 percent lower than the cumulative pot levels. The soil data are plotted on the same chart. We have a 1958 soil which is about 37, which is lagging behind by even a greater amount. But the soil sampling site has been changed since 1957 so it may not be comparable.

We now have the New York data for February and March 1959, which add nearly 7 millicuries per square mile for a total of about 63 as of the end of March.

In addition to strontium 90 the pot samples are analyzed for the shorter lived isotope strontium 89. Since May 1958, they have also been analyzed for tungsten 185, which is not a fission product and has been produced in significant amount only during our Operation Hardtack last summer. By means of these shorter lived isotopes it is possible to tell something about the age of the debris and about the test series from which it originated.

In my next chart you see the monthly fallout of strontium 89 (which has a 51 day half life) and tungsten 185 (which has a 74 day half life) at our Pittsburgh pot station. Prior to May 1958, there was essentially no tungsten 185 in the atmosphere. There was strontium 89, however, from previous fission detonations.

(The chart referred to follows:)


STRONTIUM-89 AND TUNGSTEN-185
IN PITTSBURGH FALLOUT
MILLICURIES PER SQUARE MILE
100
80
60
40
20
0
STRONTIUM-89
TUNGSTEN-185
J F M A M J J A S O N D J
1958
1959

Mr. HOLLAND. A rise in the strontium 89 in April can be attributed to the March Russian series. In June, July, August, September, and October, the course of the Operation Hardtack fallout can be observed at Pittsburgh. This series ended at the end of July, with the exception of two very high altitude detonations at Johnston Island, and a number of very low yield detonations at Nevada. During this period the strontium 89 and the tungsten 185 follow each other very closely, the only differences being attributable to the slightly more rapid decay of the strontium 89. After October, however, while the tungsten continues to go down, there is a substantial addition of strontium 89. Based on the ratio of strontium 89 to tungsten 185 in the Hardtack debris as measured from July to October the Hardtack contribution to the strontium 89 in January 1959 was about one-sixth of the total. The other five parts can be attributed to the October Russian test series.

Representative DURHAM. At that point, why do you use tungsten 185? What information does it give you?

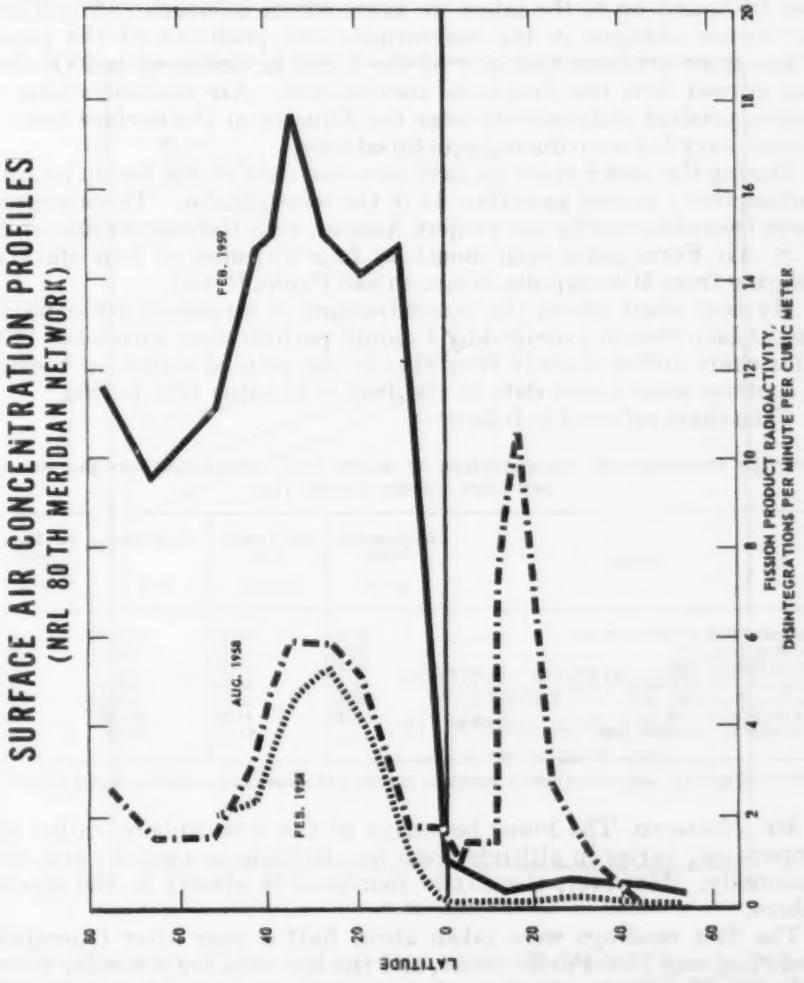
Mr. HOLLAND. Tungsten 185 as far as we know was generated in any significant quantities in only one test series, the Hardtack operation in the Pacific last summer. For this reason it enables us to distinguish debris from that test series from other fission products in the atmosphere.

Representative DURHAM. You used it as a tracer entirely?

Mr. HOLLAND. That is correct. I cannot say that was the purpose originally for which it was used. It is useful for that purpose. However, the Hardtack debris have been decaying for some 3 months longer than the U.S.S.R. debris, so the strontium 90 contributions of the U.S.S.R. and Hardtack might be equal in January. In February, however, the data indicate a further increase in the relative contribution of U.S.S.R. debris. This type of analysis is being done at many stations throughout the world. It should bring out clearly the differences in behavior of equatorial and polar debris.

Some of these differences have already been clearly shown by the measurements of surface air concentrations of radioactivity made by the Naval Research Laboratory on the 80th Meridian. Some examples of the latitudinal profiles of air radioactivity from this network, which extends from the southern tip of South America at 53° south all the way to Thule, Greenland, at 76° north, are shown in my next chart.

(The chart referred to follows:)



Mr. Holland. This shows the fission product concentration horizontally and the latitude vertically, with the North Pole at the top and the Equator in the middle. I have chosen February 1958, August 1958, and February 1959 profiles. During February 1958 a relatively low yield Soviet test series was in progress. A maximum of fission product activity is seen in the middle latitudes of the Northern Hemisphere, and very low levels in the Southern Hemisphere. August was the first month after our Hardtack series in the Pacific. Sizable peaks of surface air concentrations are seen in the middle latitudes of the Northern Hemisphere, and also at about 20° south latitude, that is, northern Chile.

Last February, 4 months after the last nuclear tests, very large concentrations of radioactivity are still seen in the entire Northern Hemisphere with a very sharp drop in the vicinity of the Equator and extremely low levels in the Southern Hemisphere. This February pattern has been duplicated in its essentials every month since Novem-

ber 1958, and up to the latest we have, which is March 1959. There are minor changes in the magnitudes and positions of the peaks. There is no evidence that any of the U.S.S.R. debris of last October has spread into the Southern Hemisphere. Air concentrations of fission product radioactivity near the Equator at the surface seem to remain very low even during equatorial tests.

During the past 2 years we have obtained data on the fission product radioactivity as well as carbon 14 in the stratosphere. These samples have been obtained by our project Ashcan, with the cooperation of the U.S. Air Force, once each month at four altitudes at four stations, ranging from Minneapolis, Minn., to Sao Paulo, Brazil.

My next chart shows the concentrations of strontium 90 at 65,000 feet at each station averaged by 4-month periods since November 1956. This chart differs slightly from that in the printed statement because it contains some newer data in the July to October 1958 period.[3]

(The chart referred to follows:)

Average strontium-90 concentration at 65,000 feet, disintegrations per minute per 1,000 standard cubic feet

Period	Minneapolis, Minn. 45° N.	San Angelo, Tex. 31° N.	Canal Zone 8° N.	Sao Paulo, Brazil 23° S.
November 1956 to February 1957	35(3)	94(2)	114(2)	32(3)
March to June 1957	63(4)	55(2)	32(3)	31(4)
July to October 1957	64(3)	47(3)	----	51(4)
November 1957 to February 1958	34(4)	46(3)	64(1)	20(3)
March to June 1958	48(3)	26(4)	38(3)	14(3)
July to October 1958	16(2)	41(2)	508(2)	46(4)
November to December 1958	----	61(1)	173(1)	----

NOTE.—Figures in parentheses denote number of months with observations available during period.

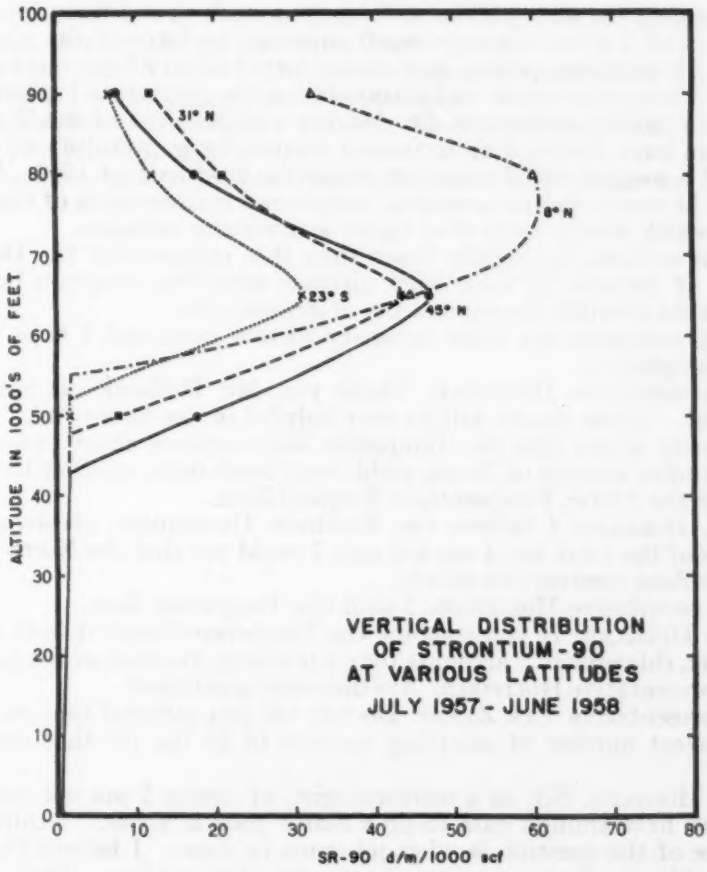
Mr. HOLLAND. The lower boundary of the stratosphere, called the tropopause, varies in altitude from one latitude to another, and also seasonally. However, the 65,000 foot level is always in the stratosphere.

The first readings were taken about half a year after Operation Redwing, our 1956 Pacific series, and the last ones are a similar interval after Hardtack. At these times there was a peak of strontium 90 concentration over our Panama station at 8° north. At other times there seems to be a general decrease from north to south.

The average vertical distribution of strontium 90 determined from the Ashcan data is shown in my next chart.

[3] This revision incorporating newer data has been made in the final chart submitted for the record.

(The chart referred to follows:)



Mr. HOLLAND. These are the data obtained directly by analysis of the samples collected on the air filters and not corrected for filtering efficiency. They show generally a maximum at the 65,000 foot sampling level at three of the stations with strong decreases up to 90,000 feet.

Only the Panama data show a maximum at a higher altitude. However, the average at this station is based on a relatively small number of samples, and may not be as accurate as the others. These decrease with altitude above 65,000 feet, though not established with certainty, are not likely to be due to decreases in filtering efficiency. On the basis of the laboratory tests of the efficiency of the filter paper used and also on the basis of theory, the filtering efficiency increases with altitude. By simultaneously sampling with highly efficient aircraft samplers and our balloon system at the same altitude, we have obtained filter efficiencies of about 20 to 25 percent at altitudes of 40,000 to 50,000 feet. By intercomparisons of the standard Ashcan which the new higher velocity balloon-borne system, we have obtained efficiencies in the neighborhood of 50 to 80 percent at 60,000 to 87,000

feet. From our laboratory tests and theory, we expect the corresponding filtering efficiency for 90,000 feet to be between 60 and 90 percent.

Based on the observations at these four stations and these four altitudes, and I stress the very small coverage we have of the globe by these 16 sampling points, and on estimated filter efficiencies such as those I have mentioned and extrapolating the pattern to highter latitudes in both hemispheres, Dr. Machta and Mr. List of the Weather Bureau have obtained an estimated stratospheric inventory of about 0.6 of a megacurie of strontium 90 in the first half of 1958. There could be errors due to occasional undetected malfunctions of the sampler which would make this figure a minimum estimate.

This estimate is slightly lower than that obtained by the Department of Defense in their high altitude sampling program but the difference is within the uncertainty of our estimate.

This completes my brief summary of new data, and I hope it has been helpful.

Representative HOLIFIELD. Thank you, Mr. Holland. It has been helpful. Those charts will be very helpful in the final print. Your testimony shows that the Temperate Zone receives about two-thirds of the total amount of fission yield from bomb tests, whether tests are held in the Arctic, Temperate, or Tropical Zone.

Mr. HOLLAND. I believe the Northern Hemisphere receives two-thirds of the total, but I am not sure I could say that the North Temperate Zone receives two-thirds.

Representative HOLIFIELD. I said the Temperate Zone.

Mr. HOLLAND. If you combine the Temperate Zones of both hemispheres, this probably accounts for quite a large fraction of the total.

Representative HOLIFIELD. Are there any questions?

Representative VAN ZANDT. Doctor, are you satisfied that we have a sufficient number of sampling stations to do the job that must be done?

Mr. HOLLAND. Sir, as a meteorologist, of course I am not satisfied that we have enough data to do a really good analysis. I think the essence of the question is what job must be done. I believe that we are making real progress in understanding this subject. There is, of course, no limit to the number of observations and the precision of observations that might be desired.

Representative VAN ZANDT. Isn't it true that as we gain knowledge in this field the field broadens and the number of stations then must be increased? In other words, let us go back a few years. Did you have as many stations then as you have today?

Mr. HOLLAND. Our program has been in operation 2 years.

Representative VAN ZANDT. In other words, the same number of stations?

Mr. HOLLAND. If you mean surface sampling stations, we did not. This has expanded steadily during the past few years. The upper air program essentially got started at that time.

Representative VAN ZANDT. Why the concentrations of material at times over the Panama Canal?

Mr. HOLLAND. The material injected into the stratosphere over essentially the same latitude seems to remain there for some months before spreading into other latitudes. This is in the stratosphere. At the surface, you notice, the radioactivity levels remain very low all

the way through the Pacific test series in the longitude of Panama. This may not be true to the west of the proving ground.

Representative VAN ZANDT. Is this related in any way to the conduct of radioactive clouds that stem from Pacific tests?

Mr. HOLLAND. Yes, sir. This is the composite result of all the individual mushroom clouds from all of the shots.

Representative HOLIFIELD. Are there any further questions? If not, thank you, Mr. Holland.

(The material used in Mr. Holland's presentation follows:)

STRONTIUM 90 DISTRIBUTION AS DETERMINED BY THE ANALYSIS OF SOILS

by

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U. S. Department of Agriculture
Plant Industry Station
Beltsville, Maryland

All of the strontium 90 results given in this report are from the Health and Safety Laboratory of the United States Atomic Energy Commission in New York City. In a number of cases soil samples have been sent through that laboratory as blind reruns. Agreement between these and the earlier values and between duplicates are excellent. It is felt that the analytical errors in the laboratory are much smaller than the errors and variability that are inevitable in field sampling. The laboratory work was done at HASL under the direction of Dr. John H. Harley, Mr. Edward Hardy, Jr. and Mr. Gerald Hamada. Mr. Edward Hardy helped in the preparation of this report and in the interpretation of the data.

Some of the foreign soils were collected by Mr. Robert Dever of the Soil Conservation Service. He, together with Dr. Vlassios Valassis and Mr. Clifford Simonson, also of the Soil Conservation Service, prepared the samples for analysis at HASL. They also did the major share of the calculations and assembling of the meteorological information. The airport sites in the United States were sampled by the HASL staff. Mr. Hal Hollister and Mr. Edward Hardy, Jr. participated in the selection and field sampling of the mid-continental transect samples. Dr. Lester Machta contributed valuable meteorological information. Mr. Franklin Newhall assembled some of the meteorological information and contributed valuable suggestions regarding sources of precipitation data.

Strontium 90 Distribution as Determined by the Analysis of Soils

Most strontium 90 reaches the surface of the earth in the water brought down from the air by rain and snow. To a lesser extent, the formation of dew on vegetation and the impingement of fog on plants make a contribution to the total amount reaching the soil. The almost complete absence of this fission product in the west coast of Chile where rainfall is essentially zero is evidence that very little strontium 90 falls out without moisture as a carrier. These statements, of course, do not apply to coarse-grained materials that may fall out close to test sites. They do apply to materials that have moved hundreds of miles either in the troposphere or the stratosphere.

Most soils retain strontium 90 against leaching by rain water in the same way that they retain the plant nutrient element calcium. There is a gradual movement of the element downward in proportion to the amount of water passing through the soil into the ground water. The process is very slow and even in areas of high rainfall it takes several years to move strontium 90 downward a few inches. Because of this retention, properly selected soils can give a good integrated value of the strontium 90 that has fallen to the ground in a selected location.

However, all soils do not stay in place during a rain storm and many soils that do stay in place do not take in the water as fast as it falls. Hence the strontium 90 that falls evenly on a given acre of soil is non-uniformly distributed after the movement of the rain water and soil has ceased. A well grassed or wooded area that is level and receives no water from higher lying ground should retain essentially all of the strontium that falls on it. A steep or stony area that absorbs little of the rainfall would retain little strontium 90.

Areas at the foot of slopes and in stream bottomlands that receive soil from higher lying ground by alluvial or colluvial action will have more strontium 90 than fell upon them in the snow and rain.

We do not know how much spread in strontium 90 content there is among the various kinds of soil units found in a given square mile of hilly landscape in the Southeastern states. It might require more effort to determine this with a reasonable degree of certainty than it has required to get a reasonable estimate of the worldwide distribution. On the other hand, a square mile of level farm land in some of the Midwestern states should have a rather even distribution of the strontium 90 that has reached the ground there.

There is a special problem in regions such as our Plains states where the winter snows drift into fence rows and hedges and

into gulleys. A smooth unprotected area loses some of the strontium 90 falling on it while the places where snow accumulates get more strontium 90 than reached them by direct deposition in snow. In such localities there are few if any sites that can be said to have the average amount for the area as a whole.

The purpose of the worldwide soil sampling program carried out by the Atomic Energy Commission with technical assistance from the Department of Agriculture, Soil Conservation Service, has been to determine how much strontium 90 has reached the surface of the earth in the various latitudes and rainfall belts. In this program no effort has been made to determine the local distribution.

Sampling for Total Strontium 90 Fallout

Sites are selected that have a good vegetative cover--usually a short grass sod--and are level or nearly so. They must be on soil that has enough base exchange capacity to hold the strontium 90, and adequate permeability to water to absorb all of the rainfall that comes down on them. Also they must have no overwash from higher ground and no potential for being flooded. Other factors that must be absent are too high a population of worms that would take some strontium 90 below sampling depth, and a tendency to open large cracks when dry. Strontium 90 in the soil at the surface will wash down into the cracks during a heavy rainstorm giving an uneven distribution and even taking some below sampling depth. There are many square miles of the earth's surface where there are few if any areas even of one one-hundredth acre in size that are suitable for this kind of sampling.

Suitable sites are frequently found in the lawns of institutions or in level meadow land. Level cultivated land can be sampled successfully but there is an added non-uniformity hazard.

In order to get a good sample one must get a representative sample. The exact area of ground surface sampled must be measured with reasonable precision because any error will be projected directly in the values found. It has been found that a satisfactory sampling of many sites can be done by taking a number of borings of precisely-known diameter to the desired depth. At present a depth of six inches gets essentially all of the strontium 90. A total area of from one to two square feet suffices.

Precision of Sampling and Analysis

Table 1 has been prepared to show the reliability of replication in the analytical laboratory of the Health and Safety Laboratory of the New York Operations Office of the Atomic Energy Commission and the

variation between paired sites at eleven different locations in various parts of the world. The pairs of sites range from 1 to 25 miles apart. Analytical duplicates agree on the average within 0.72 millicuries strontium 90 per square mile while the site variation averages 1.64 millicuries strontium 90 per square mile. The site error includes the analytical error but not the full 0.72 mc/mi^2 since duplicate determinations were used in most site values. Thus the difference between two well-selected sites in the eleven areas was approximately one mc/mi^2.

Because this list includes all of the duplicate sites with complete ground cover of vegetation and there are no evidences of gross unreliability in the data, a great deal of confidence can be placed in the single values available for most of the sampling areas.

Since all sampling sites that have been used are not of top quality according to the criteria that have been enumerated, an evaluation has been prepared for each site that has been selected and seen by the writer or his associates. These evaluations are found in the Appendix to this report. No specific evaluations have been made for most of the sites in Canada, Australia, and New Zealand that have not been visited in person. In general, however, these sites have been selected by competent soil scientists or by their direction. It is thought that these unevaluated sites are satisfactory.

1958 Results

Table 2 gives a summary of the strontium 90 values in 1958 soil samples by ten-degree latitude bands. It also shows the total precipitation during the period January 1953 through the date of collection in 1958. (January 1959 in one case.) In addition a rate of strontium 90 accumulation in relation to precipitation has been calculated and is shown. The appended data for each site give all of the information on which the calculations are based. The recorded precipitation by years is given except in a few cases where estimates are used. It is hoped that this information in the Appendix will have further usefulness to those concerned with the details of determining mechanisms of the strontium 90 distribution patterns.

Figures 1 and 2 summarize the information in Table 2 in graphic form. The inequalities between the Northern and Southern Hemisphere and the low total strontium 90 levels and rates of deposition per inch of precipitation in equatorial regions are the obvious features.

The irregularities in the average values for some latitude bands as shown in the graphs are due in some cases to samples from sites of a kind not represented in adjacent bands. For example the average for the 20 to 30°N band (Figure 1) involves the value of 79.1 mc/mi^2 strontium 90 at one location in Hawaii. The rainfall rate here is more than double that

of any other site in the Northern Hemisphere. Without this site the average value of the 20 to 30°N latitude band would have been 21.5 which is between the averages for the latitude bands on either side. This site was selected because of its high rainfall and the expected high rate of strontium 90 accumulation.

In a similar manner the 80 to 70°N latitude band in Figure 2 has a high rate of strontium 90 per inch of precipitation due to the values obtained at Cornwallis Island. The worth of these sites is questionable because of lack of complete vegetative cover and the uncertainty in the precipitation figures. Also in Figure 2 the average for the 10 to 20°S latitude is out of line with respect to the adjacent bands due to a single questionable value at Lima, Peru. However, areas of low precipitation may well have a higher rate of fallout of strontium 90 per inch of precipitation than the areas with more precipitation. Aden and Damascus are other examples. One should not discount the values of such sites completely.

If these unusual and doubtful sites and values are kept in mind it is thought that these summary graphs give a good picture of the latitudinal distribution of strontium 90 fallout in the world.

One of the weaknesses of the network of soil sampling stations is the lack of adequate representation of the large water covered areas of the earth. The data from the few sites that are far from continental land masses indicate that the fallout over water is not less per inch of precipitation than over the large land masses. Examples are found in the data from Campbell Island, Canton Island, Wake Island, and Bermuda.

The 1956-1958 Strontium 90 Increment

It is possible to make a comparison of the total strontium 90 distribution patterns in 1958 with the deposition during the two-year period 1956-1958. The data for 1956 are taken from "Environmental Contamination from Weapon Tests", HASL Report No. 42, October 1958. They do not have the same degree of reliability as the 1958 data because improved extraction procedures and soil sample preparation were used on all of the 1958 samples but only on part of the 1956 samples. The 1956 results are thought to be reasonably reliable in spite of these differences in procedures.

The 1956-1958 increment data are shown in Table 3. The time intervals between samplings are given in Table 4. Data are shown only for those sites where samples were taken at the two times indicated in Table 4.

The data of Table 3 are shown in graphic form in Figures 3 and 4. It is evident that the basic pattern of deposition of strontium 90 during the period 1956-1958 is not different from that of the total deposition period. A larger percentage of the total strontium 90 found in the Southern Hemisphere in 1958 was deposited during the last two years than was the case in the Northern Hemisphere. Figure 4 emphasizes the very low rate of deposition of strontium 90 per inch of precipitation in the equatorial regions.

Strontium 90 Data for the United States (HASL Sites) 1958

Table 5 gives partial data for the HASL soil sites at the end of October in 1958. In some cases duplicate values are available but the duplicates in most cases are not complete at this time.

The strontium 90 values for sites east of the Mississippi River and south of 40°N latitude are about 10 mc/mi^2 higher than for the world average at corresponding latitudes. However, the strontium 90 deposition per inch of rainfall is not significantly higher than the world average. The situation is similar in the Northeast where the strontium 90 values average only 3 mc/mi^2 higher than the world average. The rates of deposition per inch of rainfall during the period 1953 through sampling time in 1958 are 0.19 for the Northeast United States and 0.16 for the world at corresponding latitude, as given in Table 2. In the area between the Rocky Mountains and the Mississippi River the strontium 90 values are about 15 mc/mi^2 higher than the world average and the rate of deposition per inch of precipitation is about double the world average as shown in Table 2 for the same latitudes.

Between the Rocky Mountains and the Pacific Ocean the strontium values are the same as the world average. However, since this area is much drier than the average for the world, the rate of deposition per inch of precipitation is higher than average. As in the case of the area between the Rocky Mountains and the Mississippi River, the rate is double the world average. There is an indication of lower deposition values per inch of precipitation adjacent to the Pacific Ocean.

Strontium 90 Values Along a Mid-continental 32-inch Precipitation Transect

In late May and early June 1958 a series of soil samples were taken from a south point of Danevang, Texas, north to Ontonagon, Michigan. The sites chosen all had an average annual precipitation close to 32 inches during the five-year period 1953 through 1957.

The purpose of this study was to determine the effect of latitude on strontium deposition when precipitation is constant. The data are shown in Table 6. Higher values are found in the middle of the

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transect and lower values to the south and to the north. The same is true with respect to the rate of strontium 90 accumulation per inch of precipitation. These values represent a time of accumulation five months shorter than the other United States sites. The values agree well with other values when this time interval is considered.

Total World Strontium 90 Deposition

By using the average millicurie per square mile figures for each latitude band it is possible to calculate a total strontium 90 accumulation for the world. This is obtained by multiplying the area of the latitude band by the average value for the band. The results for 1958 at sampling time are shown in Table 7. Values for the total deposited between the sampling periods in 1956 and 1958 are also given.

An estimated increment has been added to bring 1958 foreign values forward to the end of September 1958. This was done by assuming the period April 1, 1958 to September 30, 1958 had the same rate of accumulation per month as did the 1956 to 1958 period.

In addition a calculation has been made to show how much the total strontium 90 in the United States exceeds the world average for comparable latitude and rainfall. An estimate of the excess in the USSR over world averages for comparable latitude and rainfall conditions has been made and included in the table.

The total world value including calculations and estimates is 3.2 megacuries for the amount of strontium 90 on the ground at the end of September 1958.

Table 1 REPLICATION -- 1958 DATA

	Lat.*	Precip. inches*		Distance between sites (miles)		Sr 90 mc/mi^2 Site A	Site B
Japan, Tokyo	36 N	320.5		3		a. 30.82 b. 30.03	23.47 25.76
Phillipines, Manila	15 N	354.7		4		a. 9.24 b. 8.57	7.10 6.30
Union of South Africa, Durban	30 S	239.3		2		a. 7.50 b. 6.36	6.23 7.58
Canal Zone, Panama	9 N	382.6 411.6	Site A Site B	5		a. 6.69 b. 7.53	8.57 9.45
Singapore	1 N	473.9		2		a. 4.20 b. 3.93	4.22 4.15
Belgian Congo, Leopoldville	4 S	293.6		1		a. 5.90 b. 6.15	4.80 5.01
Brazil, Belem	2 S	690	(est.)	4		a. 6.24 b. 6.66	7.25 6.07
Southern Rhodesia, Salisbury	18 S	200.5		1		a. 5.04 b. 4.84	5.34 4.55
North Dakota, Mandan	47 N	99.9		15		a. 44.80 b. 44.80	40.20 **
Alaska, Barrow	62 N	27.17		3		a. 4.29 b. **	3.52 **
Territory of Hawaii, Oahu	21 N	333.9 303.0	Site A Site B	25	0-2 in. 2-6 in. Oahu Totals	a. 21.15 b. 22.69 a. 10.03 b. 9.84 31.85	22.04 22.24 11.51 10.56 33.17

* January 1953 to date of collection 1958.
** No analytical duplicates available.

a. and b. are analytical duplicates on separate soil aliquots from same soil sample.
Average difference between analytical duplicates - 0.72 mc/mi2
Average difference between means of site duplicates- 1.64 mc/mi2
Average va'ue mc/mi^2 - 13.66

Table 2 1958 Soil Data

	Sr 90 mc/mi^2	Precip. inches*	mc Sr 90/mi^2/inch of precip.	Lat.°	Date of Sampling
80 - 70° N					
Canada - Ellesmere Is. A	2.2	19	0.116	80	8/58
Canada - Ellesmere Is. B	3.9	19	0.205	80	8/58
Canada - Cornwallis Is. A	22.1	30	0.737	75	7/58
Canada - Cornwallis Is. B	10.6	30	0.353	75	7/58
Alaska - Point Barrow A	4.3	27	0.159	71	6/58
Alaska - Point Barrow B	3.5	27	0.130	71	6/58
av.	7.8		av. 0.28		
70 - 60° N					
Norway - Bardufoss	11.4	148	0.077	69	10/58
Norway - Bodo	22.9	236	0.097	67	10/58
Alaska - Fairbanks	12.5	54	0.231	65	6/58
Iceland - Reykjavik	33.1	180	0.184	64	8/58
Alaska - Palmer	10.8	77	0.140	62	6/58
Norway - Lake Finse	23.5	269	0.087	62	9/58
Norway - Bergen	55.2	463	0.119	60+	9/58
av.	24.2		av. 0.13		
60 - 50° N					
Norway - Oslo	28.6	156	0.183	60	9/58
Canada - Lacombe, Alberta	24.2	104	0.233	53	5/58
av.	26.4		av. 0.21		
50 - 40° N					
Canada - Agassiz, B. C.	48.9	377	0.130	49	5/58
France - Paris	19.8	87	0.228	49	3/58
Canada - Saanichton, B. C.	29.8	192	0.155	49	5/58
Canada - Saint John's, N. F.	49.9	394	0.127	48	1/59
Canada - Ottawa, Ont.	22.4	171	0.131	45	5/58
Canada - Kentville, N. S.	33.8	233	0.145	45	6/58
Italy - Florence	39.8	149	0.267	44	3/58
Japan - Sapporo	33.9	254	0.133	43	2/58
av.	34.8		av. 0.16		

1958 Soil Data Page 2

40 - 30° N

	Sr 90 mc/mi²	Precip. inches*	mc Sr 90/mi²/inch of precip.	Lat.°	Date of Sampling
Turkey - Ankara	16.4	77	0.213	40	3/58
Japan - Tokyo A	30.4	320	0.095	36	2/58
Japan - Tokyo B	24.6	320	0.077	36	2/58
Lebanon- Beirut	30.4	191	0.159	34	3/58
Japan - Fukuoka	24.8	406	0.061	34	2/58
United Arab Republic - Damascus	12.9	50	0.258	33	3/58
Bermuda - Hamilton	41.4	358	0.116	32	8/58
av.	25.8	av.	0.140		

30 - 20° N

United States - Miami, Fla.	18.8	288	0.065	26	4/58
Pakistan - Karachi	7.0	48	0.146	25	3/58
India - Calcutta	14.8	274	0.054	23	2/58
Hawaii - Kahuka, Oahu Is.	23.6	227	0.104	22	2/58
Hawaii - Wahiawa, Mauka Intake, Oahu Is.	79.1	1006	0.079	22	5/58
Hawaii - Leilehua Golf Course, Oahu Is.	33.2	303	0.110	21	2/58
Hawaii - Kawailoa Girl's School, Oahu Is.	31.9	334	0.096	21	2/58
av.	29.8	av.	0.093		

20 - 10° N

Wake Island	20.2	173	0.117	19	2/58
Puerto Rico, San Juan	31.7	360	0.088	18	11/58
Senegal - Dakar	6.3	114	0.055	15	3/58
Senegal - Hann	2.6	114	0.023	15	3/58
Philippines - Manila (near water front in downtown Manila)	6.7	355	0.019	15	2/58
Philippines - Manila, Fort McKinley Cemetery	8.8	355	0.025	15	2/58
Aden	2.8	17	0.165	13	3/58
Venezuela - Caracas	5.2	167	0.031	10	2/58
av.	10.5	av.	0.065		

1958 Soil Data — Page 3

	Sr 90 mc/mi^2	Precip. inches*	mc Sr 90/mi^2/inch of precip.	Lat.°	Date of Sampling
10 - 0° N					
Panama - Fort Clayton, Canal Zone	9.0	412	0.022	9	2/58
Panama - Fort Amador, Canal Zone	7.1	383	0.018	9	2/58
Colombia - Bogota	4.7	208	0.022	5	2/58
Singapore A	4.1	474	0.009	1	2/58
Singapore B	4.2	474	0.009	1	2/58
av.	5.8	av.	0.016		
0 - 10° S					
Kenya - Kikuyu	7.3	185	0.039	1	3/58
Brazil - Belem A	6.4	564	0.011	1	3/58
Brazil - Belem, Institute B	6.7	564	0.012	1	3/58
Canton Island - near air strip A	4.7	154	0.030	3	3/58
Canton Island - near Light House B	11.3	154	0.073	3	3/58
Belgian Congo - Leopoldville A	6.0	293	0.020	4	3/58
Belgian Congo - Leopoldville B	4.9	293	0.017	4	3/58
av.	6.8	av.	0.029		
10 - 20° S					
Peru - Huancayo	6.4	151	0.042	12	2/58
Peru - Lima	2.2	10	0.220	12	2/58
Australia - Katherine	4.6	222	0.021	14	3/58
Southern Rhodesia - Salisbury A	4.9	200	0.024	18	3/58
Southern Rhodesia - Salisbury B	4.9	200	0.024	18	3/58
av.	4.6	av.	0.066		

1958 Soil Data Page 4

	Sr 90 mc/mi^2	Precip. inches*	mc Sr 90/mi^2/inch of precip.	Lat.°	Date of Sampling
20 - 30° S					
Chile - Antofagasta	0.4	0	--	23	2/58
Brazil - Sao Paulo	6.3	292	0.022	24	2/58
Australia - Alice Springs	3.0	52	0.058	24	3/58
Paraguay - Asuncion	7.5	308	0.024	25	2/58
Australia - Brisbane	11.6	249	0.046	27	3/58
Union of South Africa - Durban A	6.9	240	0.029	30	3/58
Union of South Africa - Durban, Natal Univ. B	6.9	240	0.029	30	3/58
av.	6.1		av. 0.035		
30 - 40° S					
Australia - Perth	4.7	183	0.026	32	3/58
Chile - Santiago	5.1	65	0.078	33	2/58
Argentina - Buenos Aires	11.2	197	0.057	35	2/58
Australia - Adelaide	11.7	107	0.109	35	3/58
New Zealand - North Auckland	6.4	374	0.017	36	3/58
av.	7.8		av. 0.057		
40 - 50° S					
New Zealand - Wellington	9.7	289	0.034	41	3/58
Tasmania - Hobart	11.1	149	0.074	43	3/58
New Zealand - South Canterbury	8.0	122	0.066	44	3/58
av.	9.6		av. 0.058		
50 - 60° S					
Chile - Punta Arenas	5.0	98	0.051	52	3/58
Campbell Island	13.3	305	0.044	53	3/58
av.	9.2		av. 0.048		

* from 1/1/53 through date of collection

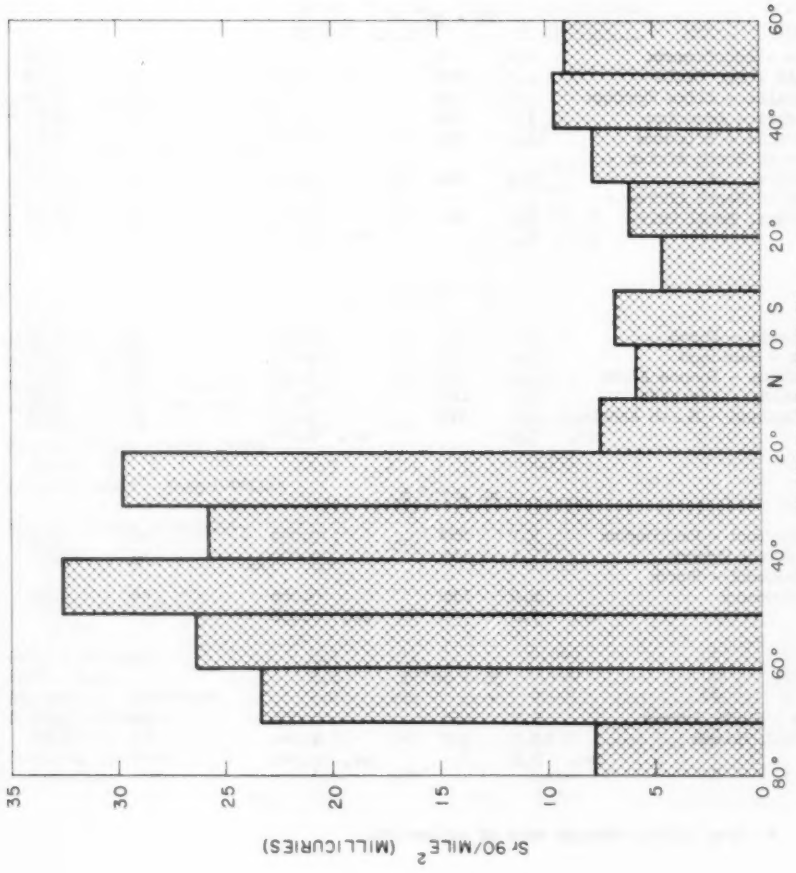

Figure 1.—Millicuries Sr 90/mile² in soil - 1958.

Figure 1.—Millicuries Sr 90/mile^2 in soil - 1958.

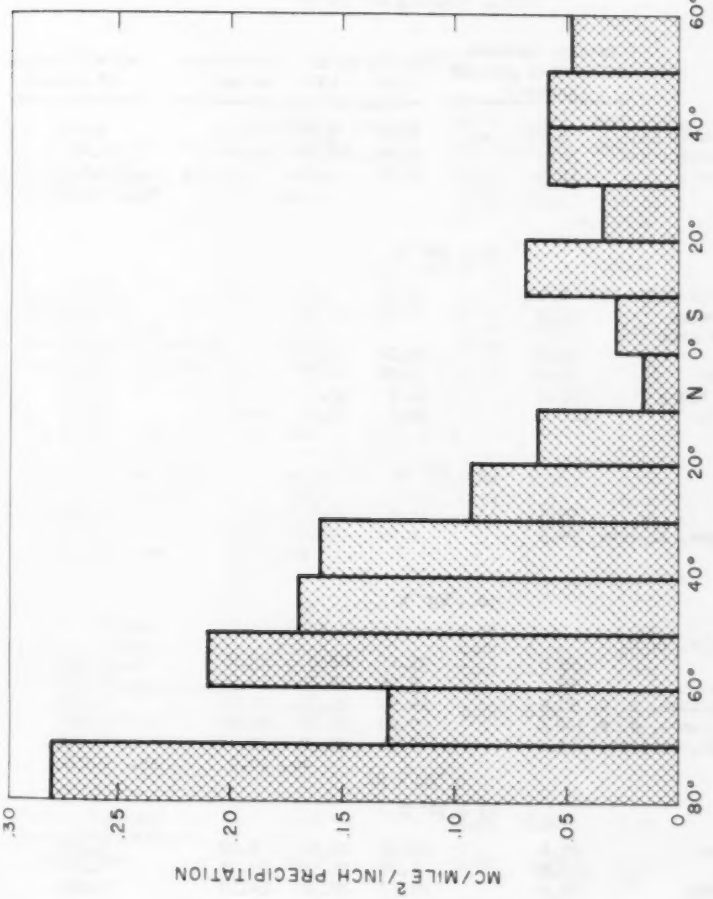

Figure 2.—Rate of Sr 90 deposition MC/mi^2/inch of precipitation 1953-1958.

Table 3 Increment and Rate of Fallout per inch of Precipitation during Period 1956 - 1958

	Precip. between collection periods (inches)	Sr 90 mc/mi² 1956	Sr 90 mc/mi² 1958	Difference mc/mi²	mc/mi²/inches of precip.
80 - 70° N					
Canada - Ellesmere Is.	5.02	2.88	3.05	0.17	0.034
Canada - Cornwallis Is.	10.6	0.86	16.35	15.49	1.46
Alaska - Barrow	12.3	2.56	3.90	1.34	0.110
			av.	5.7	av. 0.534
70 - 60° N					
Canada - Aklavik (1956-57)	8.82	2.27	[illegible]	[illegible]	[illegible]
Alaska - Fairbanks	15.2	4.23	[illegible]	[illegible]	0.544
Iceland - Reykjavik (1957-58)	38.3	16.54	33.07	[illegible]	0.432
Alaska - Palmer	25.2	5.89	10.75	[illegible]	0.193
Norway - Lake Finse	95.3	11.9	23.5	[illegible]	0.122
Norway - Bergen	118.0	35.2	55.2	[illegible]	0.169
			av.	[illegible]	av. 0.477
60 - 50° N					
Norway - Oslo	58.3	11.6	28.6	[illegible]	[illegible]
Canada - Lacombe, Alberta	26.9	8.49	24.17	[illegible]	0.583
			av.	[illegible]	av. 0.438
50 - 40° N					
Canada - Agassiz, B. C. (1957-58)	52.0	35.1	48.9	13.8	0.265
France - Paris	32.3	7.24	19.75	12.51	0.387
Canada - Saanichton, B. C.	58.2	14.98	29.81	14.83	0.255
Canada - St. John's, N. F.	162.5	9.09	49.94	40.85	0.251
Canada - Ottawa, Ontario	63.1	9.91	22.38	12.47	0.198
			av.	18.9	av. 0.271
40 - 30° N					
Turkey - Ankara	25.4	10.25	16.44	6.19	0.244
Japan - Tokyo	122.0	1.78	27.50	25.74	0.211
Lebanon - Beirut	64.2	16.17	30.36	14.19	0.221
United Arab Republic - Damascus	15.2	4.96	12.87	7.91	0.520
			av.	13.5	av. 0.299

Increment and Rate of Fallout per inch of Precipitation during Period 1956 - 1958 Page 2

	Precip. between collection periods (inches)	Sr 90 mc/mi² 1956	1958	Difference mc/mi²	mc/mi²/inches of precip.
30 - 20° N					
U.S.A. - Miami, Fla.	76.0	12.8	18.8	6.0	0.079
Hawaii - Oahu	145.0	7.72	32.55	24.83	0.171
			av.	15.4	av. 0.125
20 - 10° N					
Wake Island	59.0	8.62	20.2[illegible]	[illegible].6[illegible]	0.197
Senegal - Dakar	30.0	2.34	6.[illegible]6	[illegible].9[illegible]	0.131
Philippines - Manila	135.0	4.68	8.80	[illegible].[illegible]2	0.030
Venezuela - Caracas	48.0	2.55	[illegible].[illegible]6	[illegible].[illegible]2	0.054
			av.	[illegible].6	0.103
10 - 0° N					
Panama - Canal Zone	147.0	5.48	8.06	[illegible].[illegible]8	0.018
Colombia - Bogota	78.1	2.53	4.73	[illegible].[illegible]0	0.028
Singapore	159.0	2.89	4.[illegible]	[illegible].[illegible]6	0.008
			av.	[illegible].0	av. 0.018
0 - 10° S					
Kenya - Kikuyu	62.2	2.82	7.31	[illegible].49	0.072
Brazil - Belem	214.0	4.07	6.55	[illegible].48	0.012
Canton Island	87.8	3.46	4.69	[illegible].23	0.014
Belgian Congo, Leopoldville	93.9	3.62	6.02	[illegible].40	0.026
			av.	[illegible].6	av. 0.031
10 - 20° S					
Peru - Huancayo	60.5	1.95	6.44	4.49	0.074
Southern Rhodesia - Salisbury	66.4	2.64	4.94	2.30	0.035
			av.	3.4	av. 0.054

Increment and Rate of Fallout per inch of Precipitation during Period 1956 - 1958 Page 3

20 - 30° S

	Precip. between Collection periods (inches)	Sr 90 mc/mi² 1956	1958	Difference mc/mi²	mc/mi²/inches of precip.
Chile - Antofagasta	0.0	0.06	0.37	0.31	---
Brazil - Sao Paulo	118.0	2.6	6.3	3.7	0.031
Australia - Alice Springs	13.9	1.86	2.96	1.10	0.079
Paraguay - Asuncion	127.0	1.9	7.5	5.6	0.044
Australia - Brisbane	65.3	3.26	11.62	8.36	0.128
South Africa - Durban	92.2	4.66	6.93	[illegible]	0.045
			av.	3.5	av. 0.095

30 - 40° S

Australia, Perth	67.8	2.57	4.72	[illegible]	0.032
Chile - Santiago	22.0	1.95	5.07	[illegible]	0.149
Argentina - Buenos Aires	71.7	2.62	[illegible]	8.58	0.120
Australia - Adelaide	40.0	5.1	11.7	[illegible]	0.165
New Zealand - North Auckland	140.0	3.81	6.38	2.57	0.018
			av.	4.5	av. 0.095

40 - 50° S

New Zealand - Wellington	108.0	3.29	9.75	6.46	0.060
Tasmania - Hobart	59.9	1.33	11.13	9.80	0.164
New Zealand - South Canterbury	50.3	2.18	8.02	[illegible]	0.116
			av.	7.4	av. 0.113

50 - 60° S

Chile - Punta Arenas (110 Km N)	48.2	1.28	4.96	3.68	0.076
Campbell Island	99.3	2.27	13.27	11.0	0.111
			av.	7.3	av. 0.094

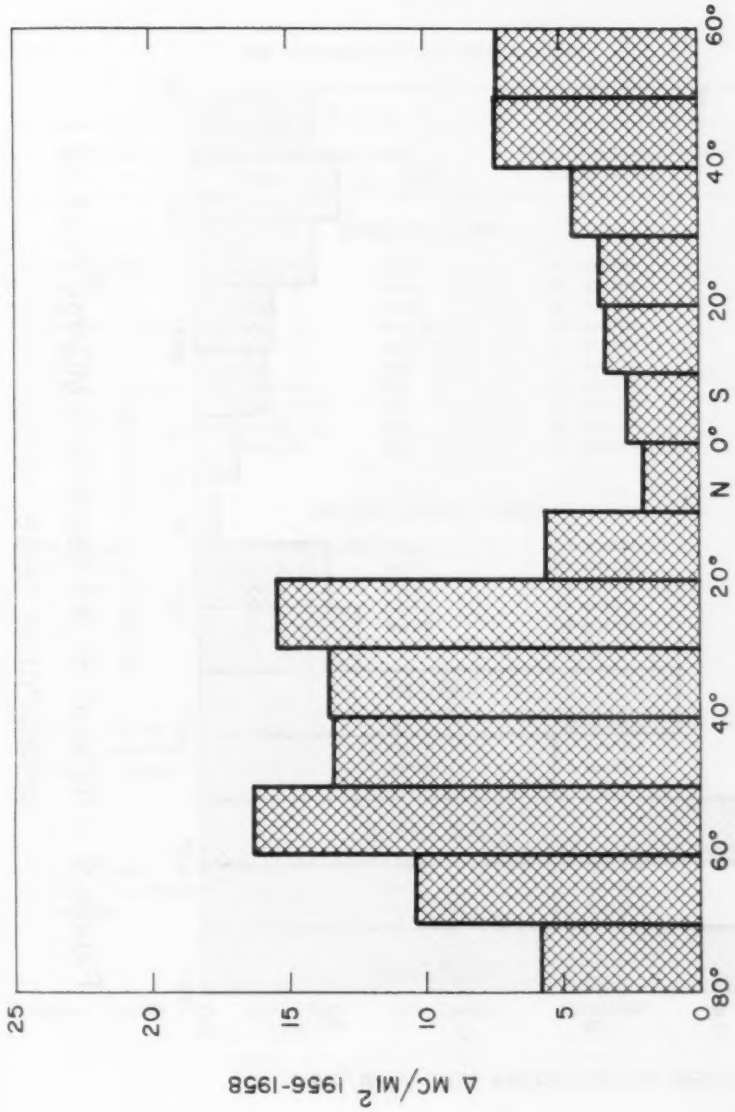

Figure 3.-Sr 90 deposited in soil during the period 1956 – 1958

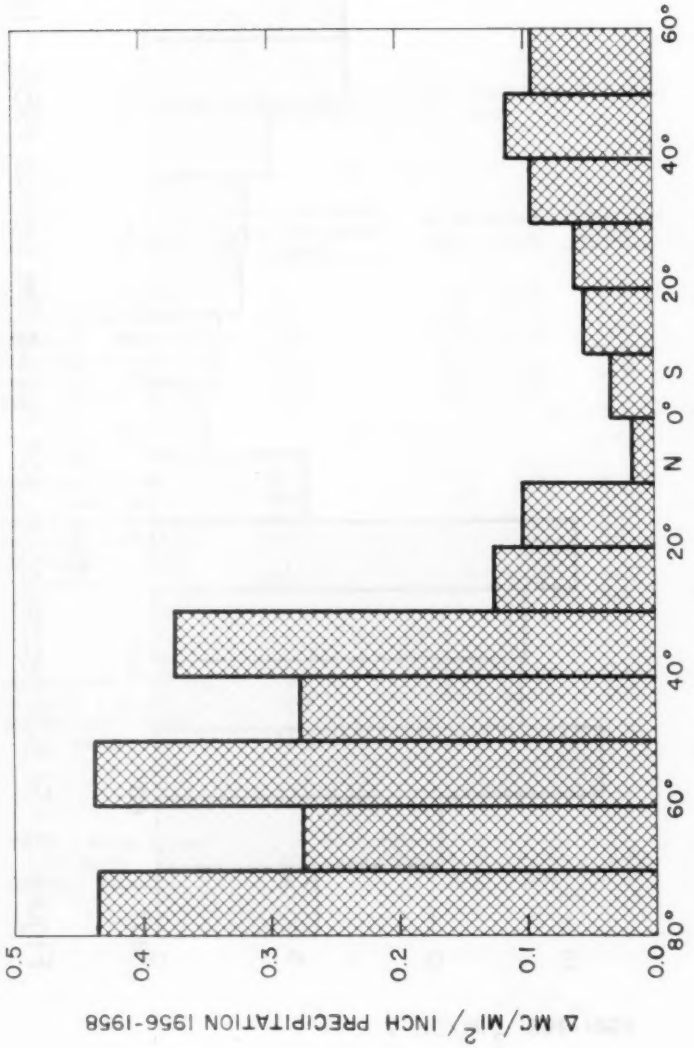

Figure 4. — Rate of Sr 90 deposition MC/mi^2/inch of precipitation 1956–1958.

Table 4 Time between 1956 and 1958 sampling

Station	Sampling Dates 1956	1958	Precipitation Period (Length of)	Latitude
		Alaska and Canada		
Point Barrow	Aug. 10	June	23 months	71° N
Fairbanks	Aug. 8	June	23 months	65° N
Palmer	Aug. 6	June	23 months	62° N
Ellesmere Island	Aug. 12	early Aug.	24 months	80° N
Cornwallis Island	Aug. 12	late July	24 months	75° N
Aklavik	Aug. 15	Aug. 1957	12 months	68° N
Lacombe, Alberta	late Aug.	May	21 months	53° N
Agassiz, B. C.	June 1957	May	12 months	49° N
Saanichton, B. C.	early Aug.	May	22 months	49° N
Ottawa	May 14	May	25 months	45° N
		Iceland, Norway, France		
Revkjavik	June 27, 1957	Aug.	14 months	64° N
Lake Finse	Sept. 2	Sept.	25 months	61° N
Bergen	Feb. 25, 1957	Sept.	19 months	60° N
Oslo	Aug. 26	Sept.	25 months	59° N
Paris	Sept. 4	March	19 months	49° N
		Near East		
Ankara, Turkey	Oct. 4	March	18 months	39° N
Beirut, Lebanon	Oct. 1	March	18 months	34° N
Damascus, Syria	Oct. 2	March	18 months	34° N
		Eastern Asia		
Tokyo, Japan	Apr. 4	Feb.	23 months	36° N
Manila, Philippines	Apr. 9	Feb.	23 months	15° N
Singapore	Apr. 13 - Apr. 15	mid-Feb.	22 months	1° N
		United States		
Miami, Florida	early Apr. 1957	late in Apr.	13 months	26° N

precipitation 1956—1958.

Time between 1956 and 1958 sampling

Station	Sampling Dates 1956	1958	Precipitation Period (Length of)	Latitude
Pacific Islands				
Wake Island	Apr. 2	Feb.	23 months	20° N
Oahu, Hawaii	Nov. 23, 1955	Feb.	27 months	22° N
Canton Island	Apr. 27	Feb.	22 months	3° S
Africa				
Dakar, Senegal	Sept. 10	March	19 months	15° N
Kenya	Sept. 27	March	18 months	1° S
Leopoldville, Belgian Congo	Sept. 11	March	19 months	4° S
Salisbury, Southern Rhodesia	Sept. 17	March	18 months	18° S
Durban, South Africa	Sept. 14	March	19 months	30° S
Latin America				
Caracas, Venezuela	Feb. 2	Feb.	25 months	10° N
Panama	Jan. 3	Feb.	25 months	9° N
Bogota, Colombia	Jan. 6	Feb.	25 months	5° N
Belem, Brazil	Jan. 31	March	26 months	1° S
Huancayo, Peru	Feb. 9	Feb.	25 months	12° S
Antofagasta, Chile	Jan. 13	Feb.	25 months	24° S
Sao Paulo, Brazil	Jan. 30	Feb.	25 months	24° S
Asuncion, Paraguay	late Jan.	Feb.	25 months	25° S
Santiago, Chile	Jan. 16	Feb.	25 months	33° S
Buenos Aires, Argentino	Jan. 18	Feb.	25 months	35° S
Punta Arenas, Chile	Jan. 23	March	26 months	52° S
Australia, New Zealand and Campbell Island				
Alice Springs	June 19	March	21 months	24° S
Brisbane	May 8	March	23 months	28° S
Perth	prior to May 10	March	23 months	32° S
Adelaide	May 7	March	23 months	35° S
North Auckland	May 10	March	23 months	36° S
Wellington	Apr. 24	March	23 months	41° S
Hobart	May 6	March	23 months	43° S
South Canterbury	Apr. 27	March	23 months	44° S
Campbell Island	early July	March	21 months	53° S

Table 5 STRONTIUM 90 IN UNITED STATES SOILS - HASL SITES
(Sampled October 1958)

Location	Site	mc Sr 90/mi^2	av.	Precip.* (Inches)	mc Sr 90/mi^2/in. precip.	av. rate	Lat.°
50 - 40° N							
Seattle, Wash.	A	33.5	29.8	236	0.142	0.137	47
	B	26.1		198	0.132		
Rapid City, S. D.	A	75.0	73.8	96.2	0.779	0.732	44
	B	72.5		106	0.686		
Boise, Id.	A	35.6	38.4	70.6	0.505	0.546	44
	B	41.3		70.6	0.586		
Rochester, N. Y.		33.0	33.0	187	0.177	0.177	43
Detroit, Mich.		39.5	39.5	174	0.227	0.227	42
Binghamton, N. Y.	A	40.5	40.0	216	0.187	0.184	42
	B	39.4		216	0.182		
Des Moines, Ia.		55.7	55.7	150	0.371	0.371	41
Salt Lake City, Ut.		78.0	78.0	95.4	0.817	0.817	41
New York, N. Y.		36.6	36.6	231	0.158	0.158	40
Philadelphia, Pa.		44.0	44.0	240	0.183	0.183	40
Average			46.9			0.353	
40 - 30° N							
Grand Junction, Colo.		38.9	38.9	51.6	0.754	0.754	39
Memphis, Tenn.		36.8	36.8	321	0.114	0.114	35
Albuquerque, N. M.		26.8	26.8	39.2	0.685	0.685	35
Atlanta, Ga.		36.9	36.9	260	0.142	0.142	34
Los Angeles, Calif.	A	16.6	19.0	67.2	0.246	0.268	34
	B	21.4		74.0	0.289		
New Orleans, La.	A	28.9	34.2	333	0.087	0.098	30
	B	39.4		365	0.108		
Jacksonville, Fla.		36.0	36.0	301	0.120	0.120	30
Average			32.6			0.311	

*1953 through date of sampling.
Strontium 90 values are from Health and Safety Laboratory, New York.

Table 6 STRONTIUM 90 IN SOILS AT 32 INCH AVERAGE PRECIPITATION SITES
(Mid-United States Collections - 5-26-58 through 6-5-58)

Location	mc Sr 90/mi^2	Precip.* (Inches)	mc Sr 90/mi^2/in. precip.	Lat.°
Ontonagon, Mich.	32.7	198	0.165	47
Antigo, Wisc.	31.4	181	0.173	45
Portage, Wisc.	34.6	182	0.190	43
Marengo, Ill.	36.0	174	0.207	42
Galva, Ill.	38.1	201	0.190	41
Springfield, Ill.	58.0	198	0.293	40
Columbia, Mo.	46.0	196	0.235	39
Bolivar, Mo.	41.7	210	0.198	37
Tulsa, Okla.	48.0	208	0.231	36
Chandler, Okla.	49.4	204	0.242	36
Marlow, Okla.	44.8	208	0.215	35
Slidell, Tex.	45.8	212	0.216	33
Sanger, Tex.	57.2	201	0.284	33
Ferris, Tex.	43.2	223	0.194	32
Thornton, Tex.	32.6	209	0.156	32
Dime Box, Tex.	30.0	201	0.149	31
Brenham, Tex.	22.5	204	0.110	30
Danevang, Tex.	26.3	216	0.122	29

*1953 through May 1958.

Strontium 90 values are from Health and Safety Laboratory, New York.

Table 7 WORLD-WIDE Sr^{90} DEPOSITION IN SOILS

TO SAMPLING DATE 1958

Lat. (°)	Total		1956-1958 Increment	
	mc/mi^2	Megacuries by Latitude Bands	mc/mi^2	Megacuries by Latitude Bands
80-70 N	7.8	0.034	5.7	0.025
70-60 N	24.2	0.174	10.5	0.076
60-50 N	26.4	0.259	16.3	0.160
50-40 N	34.8	0.425	18.9	0.231
40-30 N	25.8	0.364	13.5	0.190
30-20 N	29.8	0.465	15.4	0.240
20-10 N	10.5	0.174	5.6	0.093
10- 0 N	5.8	0.099	2.0	0.034
0-10 S	6.8	0.116	2.6	0.044
10-20 S	4.6	0.076	3.4	0.056
20-30 S	6.1	0.095	3.6	0.056
30-40 S	7.8	0.110	4.6	0.065
40-50 S	9.6	0.117	7.4	0.090
50-60 S	9.2	0.090	7.3	0.072
	Totals	2.598		1.432

Data from the Continental United States not used except from Miami.

Estimates	mc/mi^2	Megacuries Sr^{90}
90-80 N	5	0.008
60-70 S	8	0.058
70-80 S	6	0.026
80-90 S	4	0.006
Extra for Apr-Sept.1958		0.358
Extra for U.S. over average		0.047
Extra for U.S.S.R. over average		0.095
Total megacuries Oct. 1, 1958 from calculations and estimates		3.196

Significant figures: 3.2 megacuries

APPENDIX

	Information Sheet No.
Adelaide, Australia	63
Aden	40
Agassiz, B. C., Canada	13
Alice Springs, Australia	56
Ankara, Turkey	21
Antofagasta, Chile	54
Asuncion, Paraguay	57
Bardufoss, Norway	4
Beirut, Lebanon	23
Belem, Brazil Sites A and B	47
Bergen, Norway	10
Bodo, Norway	5
Bogota, Colombia	44
Brisbane, Australia	58
Buenos Aires, Argentina	62
Calcutta, India	29
Campbell Island	69
Canton Island Sites A and B	48
Caracas, Venezuela	41
Cornwallis Island, Canada Sites A and B	2
Dakar, Senegal	36
Damascus, United Arab Republic	25
Durban, Union of South Africa, Sites A and B	59
Ellesmere Island, Canada, Sites A and B	1
Fairbanks, Alaska	6
Florence, Italy	19
Fort Amador, Canal Zone, Panama	43
Fort Clayton, Canal Zone, Panama	42
Fukuoka, Japan	24
Hamilton, Bermuda	26
Hann, Senegal	37
Hobart, Tasmania	66
Huancayo, Peru	50
Kahuku, Oahu, Hawaii	30
Karachi, Pakistan	28
Katherine, Australia	52
Kawailoa, Girls School, Oahu, Hawaii	33
Kentville, N. S., Canada	18
Kikuyu, Kenya	46
Lacombe, Alberta, Canada	12
Lake Finse, Norway	9
Leilehua Golf Course, Oahu, Hawaii	32
Leopoldville, Belgian Congo Sites A and B	49
Lima, Peru	51
Manila, Philippines, Near waterfront in downtown Manila	38
Manila, Philippines, Fort McKinley Cemetery	39
Miami, Florida, U. S. A.	27
North Auckland, New Zealand	64
Oslo, Norway	11
Ottawa, Ontario, Canada	17
Palmer, Alaska	8
Paris, France	14
Perth, Australia	60
Point Barrow, Alaska, Sites A and B	3
Punta Arenas, Chile	68
Reykjavik, Iceland	7
Saanichton, B. C., Canada	15
Saint Johns, N. F., Canada	16
Salisbury, Southern Rhodesia, Sites A and B	53
San Juan, Puerto Rico	35
Santiago, Chile	61
Sao Paulo, Brazil	55
Sapporo, Japan	20
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Tokyo, Japan, Sites A and B	22
Wahiawa, Oahu, Hawaii, Mauka Intake	31
Wake Island	34
Wellington, New Zealand	65

EUREKA, ELLESMERE ISLAND, CANADA

Latitude: 80°00'N **Longitude:** 85°56'W (Weather Station)

	SITE A	SITE B
1958 Date of Sampling:	August	August
Sampled Area (Sq. Feet):	1.34	1.34
Depth Sampled (Inches):	0-6	0-6
Total Air-dried Weight of Sample (Lbs.):	27.3	28.5
Beltsville Number:	58847	58848
1958 d/m Sr 90/Kg of soil:	19:00	32:00
mc Sr 90/mi^2:	2.2	3.9
Previous Sampling:	8/12/56	8/12/56

Total Precipitation* (Inches)

1953	6.60
1954	4.60
1955	2.43
1956	2.01
1957	3.01
1958 Jan.-Aug.	0.67
Total:	19.32

These samples were collected by personnel of the United States Weather Bureau. The samples were taken in the occasional clumps of vegetation that occur in this very cold, very dry region. Because there is not a complete vegetative cover the snow drifts a great deal. More would be expected to accumulate in the vegetated areas than on the bare ground. These sites are not good. Perhaps good soil samples cannot be taken in these areas.

*Ellesmere Island Weather Station

RESOLUTE BAY, CORNWALLIS ISLAND, CANADA

Latitude: 74°43'N Longitude: 94°59'W (Weather Station)

	SITE A	SITE B
1958 Date of Sampling:	July	July
Sampled Area (Sq. Feet):	1.34	1.34
Depth Sampled (Inches):	0-6	0-6
Total Air-dried Weight of Sample (Lbs.):	43.0	75.0
Beltsville Number:	581040	581041
1958 d/m Sr 90/Kg of soil:	120.94	33.14
mc Sr 90/mi^2:	22.1	10.6
Previous Sampling:	8/12/56	8/12/56

Total Precipitation* (Inches)

1953	4.79
1954	7.48
1955	4.91
1956	5.66
1957	4.96
1958 Jan.-July	2.13
Total:	29.93

These samples were collected by personnel of the United States Weather Bureau. The samples were taken in the occasional clumps of vegetation that occur in this very cold, very dry region. Because there is not a complete vegetative cover the snow drifts a great deal. More would be expected to accumulate in the vegetated areas than on the bare ground. These sites are not good. Perhaps good soil samples cannot be taken in these areas.

*Cornwallis Island Weather Station

POINT BARROW, ALASKA

Latitude: 71°18'N Longitude: 156°47'W (Weather Station)

	SITE A	SITE B
1958 Date of Sampling:	June	June
Sampled Area (Sq. Feet):	0.98	0.98
Depth Sampled (Inches):	0-6	0-6
Total Air-dried Weight of Sample (Lbs.)	6.5	8.0
Beltsville Number:	58439	58472
1958 d/m Sr 90/Kg of soil:	113.58	75.74
mc Sr 90/mi^2:	4.3	3.5
Previous Sampling:	8/10/56	8/10/56

Total Precipitation* (Inches)

1953	2.74
1954	5.52
1955	4.53
1956	4.35
1957	7.51
1958 Jan-June	2.52
Total:	27.17

The two sites are in similar positions on frost mounds that are about thirty feet across. There is a complete vegetative cover. The sites are considered quite good. The height of the vegetative cover of grasses, sedges, and willow varies with the intensity of grazing by rodents. There may be some blowing of snow in the winter. The areas have not been disturbed by man. Occasionally there is a spewing of the soil material due to pressure within the mounds. These newly spewed spots are easy to spot and they heal very slowly. In sampling they were avoided.

*Point Barrow Weather Station

BARDUFOSS, NORWAY

Latitude: 69°05'N Longitude: 18°31'E

1958 Date of Sampling:	October
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	36.5
Beltsville Number:	581029
1958 d/m Sr 90/Kg of soil:	73.40
mc Sr 90/mi^2:	11.4
Previous Sampling:	None

Total Precipitation* (Inches)

1953		34.37
1954		22.24
1955		25.67
1956		25.94
1957		24.49
1958	Jan.-Sept.	15.39
	Total:	148.10

The sampling site is in a virgin woodland near the weather station. The trees are scattered Scots pine with a dense undercover of heather, blueberries and mosses. The trees are not large enough nor thick enough to cause sheltering. The undercover is adequate to prevent drifting of snow. This is an excellent site.

*Bardufoss Weather Station

BODO, NORWAY

Latitude: 67°17'N **Longitude:** 14°24'E

1958 Date of Sampling:	October
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	19.5
Beltsville Number:	581027
1958 d/m Sr 90/Kg of soil:	275.76
mc Sr 90/mi^2:	22.9
Previous Sampling:	None

Total Precipitation* (Inches)		
1953		48.07
1954		39.41
1955		42.91
1956		33.07
1957		43.07
1958	Jan.-Sept.	29.57
	Total:	236.10

This site is across the road from the weather station. The soil material is fill over peat. It has not been disturbed recently. There was a good cover of grasses and sedges. Because of the position of the road there might be some drifting of snow. However, the site is considered good.

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* Bodo Weather Station

FAIRBANKS, ALASKA

Latitude: 64°49'N Longitude: 147°52'W (Weather Station)

1958 Date of Sampling:	June
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	36.0
Beltsville Number:	58437
1958 d/m Sr 90/Kg of soil:	81.38
mc Sr 90/mi^2:	12.5
Previous Sampling:	8/8/56

Total Precipitation* (Inches)	
1953	8.99
1954	10.17
1955	15.86
1956	11.37
1957	5.43
1958 Jan.-June	1.97
Total:	53.79

The sampling site is in the front yard of the Superintendent's residence at the Agricultural Experiment Station. There may be some loss or gain of snow due to drifting in winter. The site was good for sampling in 1958. Gravel at a depth of 5 to 6 inches will prevent deeper sampling. The site is considered good.

*Fairbanks (city) Weather Station. Soil sample site is 4 miles west of Fairbanks.

REYKJAVIK, ICELAND

Latitude: 64°08'N Longitude: 21°57'W (Weather Station)

1958 Date of Sampling:	August
Sampled Area (Sq. Feet):	1.13
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	16.0
Beltsville Number:	58474
1958 d/m Sr 90/Kg of soil:	409.92
mc Sr 90/mi^2:	33.1
Previous Sampling:	None

Total Precipitation* (Inches)	
1953	42.52
1954	30.28
1955	25.20
1956	36.61
1957	32.01
1958 Jan.-Aug.	13.39
Total:	180.01

The sampling site is in a permanent grass field (hay field) of the Institute for Experimental Pathology at Keldur, about 8 km. southeast from Reykjavik, where the weather station is located. The soil is a drained, deep peat soil containing approximately 50 percent mineral matter. The soil has not been disturbed for the past ten years at least. The surface has 2 to 3 percent slope. Most of the precipitation in this area comes down as rain. As in most locations in Iceland, any snow cover will drift, more or less, because of practically continuous winds.

*Reykjavik Weather Station

PALMER, ALASKA

Latitude: 61°34'N Longitude: 149°16'W

1958 Date of Sampling:	June
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	32.5
Beltsville Number:	58438
1958 d/m Sr 90/Kg of soil:	77.80
mc Sr 90/mi^2:	10.8
Previous Sampling:	8/6/56

Total Precipitation* (Inches)

1953	12.33
1954	14.50
1955	16.60
1956	14.30
1957	15.37
1958 Jan.-June	3.90
Total:	77.00

The sample was collected in a small area at the Agricultural Experiment Station that is outside the cultivated areas. It has a good cover of grass. There is rather severe rodent activity in the area. These disturbed areas were avoided to the extent that they were evident. There may be some snow drifting in any open area such as this. In spite of these possible drawbacks the site and sample are considered good.

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*Matanuska Valley Station No. 14 (Agricultural Experiment Station)

LAKE FINSE, NORWAY

Latitude: 60°37'N Longitude: 7°29'E

1958 Date of Sampling:	September
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-3-6
Total Air-dried Weight of Sample (Lbs.):	12.5
Beltsville Number:	581026
1958 d/m Sr 90/Kg of soil:	442.04
mc Sr 90/mi^2:	23.5
Previous Sampling:	9/2/56

Total Precipitation* (Inches)		
1953		58.23
1954		49.25
1955		34.06
1956		48.39
1957		57.44
1958	Jan.-Sept.	21.73
	Total:	269.10

The site is at the west end of the Lake Finse. The country is so rugged and windswept that there are no good sites. This one is in a small rock sheltered bit of meadow just below the permanent snow line. It is unlikely that the strontium falling on this site is correctly represented by that found in the sample. One cannot say, however, whether it is more likely to be low or high. This was the best site to be found here.

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*Finse (Slira) Weather Station

BERGEN, NORWAY

Latitude: 60°24'N Longitude: 5°19'E (Weather Station)

1958 Date of Sampling:	September
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	41.0
Beltsville Number:	581028
1958 d/m Sr 90/Kg of soil:	316.62
mc Sr 90/mi^2	55.2
Previous Sampling:	2/25/57

Total Precipitation* (Inches)		
1953		99.84
1954		83.11
1955		71.38
1956		75.59
1957		93.62
1958	Jan.-Sept.	39.29
	Total:	462.83

This sample was taken in Nygards Park in the city of Bergen. The park is quite rolling and there are few good sites. The one sampled in 1958 is almost level. It has not been disturbed. However, there is some sheltering from the trees. The site is covered by a good turf of grass. The site and sample are rated good.

*Fredericksburg Weather Station, Bergen, which is northwest of soil sample site by 1' of latitude and 2' of longitude.

OSLO, NORWAY

Latitude: 59°56'N Longitude: 10°51'E (Sample site)

1958 Date of Sampling:	September
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.)	53.0
Beltsville Number:	581025
1958 d/m Sr 90/Kg of soil:	127.10
mc Sr 90/mi^2:	28.6
Previous Sampling:	8/26/56

Total Precipitation* (Inches)

1953	28.66
1954	35.12
1955	21.14
1956	20.87
1957	30.16
1958 Jan.-Sept.	19.69
Total:	155.64

This site is in the garden of a residence in the outskirts of the city of Oslo. The sampling area is between the rows of young fruit trees. The soil is a loam with adequate capacity to hold strontium 90. It has not been disturbed during the period of deposition of strontium 90. As sampled in 1956 the site was excellent. It was good to excellent in 1958. It will become progressively poorer as a site because of the increase in sheltering by the rapidly growing fruit trees. There is an excellent grass sod.

*Blindern Weather Station, Oslo which is due west of soil sample site by 7' longitude.

LACOMBE, ALBERTA, CANADA

Latitude: 52°58'N Longitude: 113°44'W

1958 Date of Sampling:		May
Sampled Area (Sq. Feet):		1.34
Depth Sampled (Inches):	a.	0-1
	b.	1-6
Total Air-dried Weight of Sample (Lbs.)	a.	8.0
	b.	52.0
Beltsville Number:		58385
		58386
1958 d/m Sr 90/Kg of soil:	a.	431.92
	b.	42.86
mc Sr 90/mi^2:	a.	14.69
	b.	9.48
	Total:	24.2

Previous Sampling: 8/19/56

Total Precipitation* (Inches)

1953		22.03
1954		21.39
1955		20.52
1956		19.86
1957		14.33
1958	Jan.-May	5.92
	Total	104.05

This is a site on the Canadian Agricultural Experiment Station near Lacombe. The detail selection of this permanently grassed site was made by the Experiment Station Staff. They also collected the samples.

*Lacombe Experimental Farm rain gauge, which is very near the soil sample site.

AGASSIZ, B. C., CANADA

Latitude: 49°13'N **Longitude:** 121°46'W

1958 Date of Sampling:	May
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches)	0-6
Total Air-dried Weight of Sample (Lbs.)	49.5
Beltsville Number:	58387
1958 d/m Sr 90/Kg of soil:	232.04
mc Sr 90/mi^2:	48.8
Previous Sampling:	8/56 6/57

Total Precipitation* (Inches)

1953		84.55
1954		70.76
1955		72.96
1956		77.79
1957		45.25
1958	Jan.-May	25.61
	Total:	376.92

The sampling site is in a lawn area on the grounds of the Canadian Experiment Station near Agassiz. The excellent blue grass sod has been undisturbed during the period of strontium 90 deposition. The soil has a favorable texture for retaining strontium 90. The site is considered excellent.

*Agassiz Dominion Experimental Farm rain gauge, which is very close to the soil sample site.

PARIS, FRANCE

Latitude: 48°58'N Longitude: 02°27'E (Weather Station)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.)	42.5
Beltsville Number:	58203
1958 d/m Sr 90/Kg of soil:	111.96 106.56
mc Sr 90/mi^2:	20.23 19.25
Average:	19.7
Previous Sampling:	2/16/55 9/ 4/56

Total Precipitation* (Inches)

1953		11.72
1954		14.51
1955		17.16
1956		16.54
1957		19.90
1958	Jan.-Mar.	6.85
	Total:	86.68

This site is the lawn of an old residence near the center of Paris. The area has not been disturbed during the time of deposition of strontium 90. The sod is blue grass and is quite dense. There is a small amount of sheltering by large high trees. Worms are a problem in this lawn. There are many areas when the soil has been severely disturbed by them. An effort was made to avoid any disturbance by the worms. The worms would cause heterogeneity in the strontium 90 distribution and would take some below sampling depth. For these reasons the site is considered as only fair.

*LeBourget Weather Station, Paris

SAANICHTON, B.C., CANADA

Latitude: 48°39'N Longitude: 123°24'W

1958 Date of Sampling:	May
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	63.0
Beltsville Number:	58318
1958 d/m Sr 90/Kg of soil:	111.30
mc Sr 90/mi^2:	29.8
Previous Sampling:	8/1956

Total Precipitation (Inches)		
1953		39.47
1954		38.44
1955		36.25
1956		33.57
1957		29.38
1958	Jan.-May	14.82
	Total:	191.93

This site is on the Canadian Agricultural Experiment Station. The sampling area has been undisturbed during the period of deposition of the strontium 90. The site selection and sampling were done by Experiment Station staff members.

*Sidney (Saanichton) Weather Station

ST. JOHNS, NEWFOUNDLAND, CANADA

Latitude: 47°32'N Longitude: 52°47'W

1959 Date of Sampling:	January 9
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	34.0
Beltsville Number:	.5986
1958 d/m Sr 90/Kg of soil:	345.42
mc Sr 90/mi^2:	49.9
Previous Sampling:	10/3/56

Total Precipitation* (Inches)	
1953	69.33
1954	57.97
1955	84.11
1956	67.81
1957	57.22
1958	57.86
Total	394.30

This is a site on the Canadian Agricultural Experiment Station near St. Johns. The detail selection of this permanently grassed site was made by the Experiment Station Staff. They also collected the samples.

*St. Johns Weather Station, which is near the soil sample site.

OTTAWA, ONTARIO, CANADA

Latitude: 45°24'N **Longitude:** 75°43'W

1958 Date of Sampling:	May
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	43.5
Beltsville Number:	58270
1958 d/m Sr 90/Kg of soil:	121.04
mc Sr 90/mi^2:	22.4
Previous Sampling:	5/14/56 4/1957

Total Precipitation* (Inches)

1953	29.91
1954	39.23
1955	28.02
1956	31.97
1957	31.51
1958 Jan.-May	10.27
Total:	170.91

This sampling site is in the lawn in front of the Administration Building of the Central Experimental Farm at the south edge of Ottawa. It is covered by an excellent grass sod and has not been disturbed in many years. This is an excellent site. Sampling to a greater depth than 6 inches would not be possible because of underlying gravel.

*Central Experimental Farm rain gauge, Ottawa, which is very near the soil sample site.

KENTVILLE, NOVA SCOTIA, CANADA

Latitude: 45°04'N Longitude: 64°36'W

1958 Date of Sampling:	June
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	47.5
Beltsville Number:	58408
1958 d/m Sr 90/Kg of soil:	167.28
mc Sr 90/mi^2:	33.8
Previous Sampling:	None

Total Precipitation* (Inches)

1953	36.95
1954	51.59
1955	31.66
1956	43.15
1957	43.88
1958 Jan.-June	26.21
Total:	233.44

This site is on the grounds of the Canadian Agricultural Experiment Station near Kentville. The area is a grass sod that has not been disturbed during the period of deposition of strontium 90. The soil contains adequate clay for holding strontium 90. This is an excellent site.

*Kentville Weather Station. No data for 1954, so the 1954 total from the Greenwood Station (44°59'N 64°55'W) is used instead.

FLORENCE, ITALY

Latitude: 43°47'N Longitude: 11°15'E (Weather Station)

1958 Date of Sampling:		March
Sampled Area (Sq. Feet):		1.34
Depth Sampled (Inches):		0-6
Total Air-dried Weight of Sample (Lbs.):		49.0
Beltsville Number:		58202
1958 d/m Sr 90/Kg of soil:		187.20 194.82
mc Sr 90/mi^2:		39.02 40.60
	Average:	39.8
Previous Sampling:		None

Total Precipitation* (Inches)

1953		35.59
1954		30.77
1955		26.38
1956		29.73
1957		18.80
1958	Jan.-Mar.	8.15
	Total:	149.42

The site is in a small, old orchard area of a residential yard and it has a fairly good grass sod. There is little sheltering from the trees. The soil contains enough clay to hold the strontium 90. The site has not been disturbed during the period of strontium 90 deposition. There is a little more slope to the area than is desirable but over-wash is prevented by small diversion ditches. The site is rated fair to good.

*Ximeniano Weather Station, Florence

SAPPORO, JAPAN

Latitude: 43°03'N Longitude: 141°20'E (Weather Station)

1958 Date of Sampling:	February
Sampled Area (Sq. Feet):	1.0
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	25.0
Beltsville Number:	58186
1958 d/m Sr 90/Kg of soil**:	235.70 247.40 231.22 236.73
mc Sr 90/mi^2:	33.58 35.24 32.94 33.72
Average:	33.9
Previous Sampling:	None

Total Precipitation* (Inches)

1953		52.4
1954		41.7
1955		53.1
1956		45.1
1957		48.9
1958	Jan.-Feb.	13.2
	Total:	254.4

This sample was taken in a small grassed yard in the city of Sapporo. There is some sheltering by trees but it is in a rather open aspect. The strontium 90 contained in the snow, which fell from December 1957 until February 1958, is not included because the snow was shoveled off before sampling. Because of the sheltering and the smallness of the area the site is rated as only good. The distance between the site and the weather station is more than is desirable.

*Sapporo (Chitose Airport) Weather Station

**Analyzed twice in duplicate - once as a blind rerun.

ANKARA, TURKEY

Latitude: 39°57'N Longitude: 32°53'E (Weather Station)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	28.0
Beltsville Number:	58219
1958 d/m Sr 90/Kg of soil:	124.33 151.82
mc Sr 90/mi^2:	14.80 18.08
Average:	16.4
Previous Sampling:	2/7/55 10/4/56

Total Precipitation* (Inches)

1953		13.41
1954		14.92
1955		15.72
1956		10.08
1957		16.24
1958	Jan.-Mar.	6.69
	Total:	77.12

This site is in the yard of a residence in Ankara. The heavy grass sod has not been disturbed during the period of deposition. The yard has fruit trees. Sampling is between the rows of trees. There is a small amount of sheltering by the trees. In the past the area has been built up by fill containing some brick fragments that interfere somewhat with good sampling. Because of these deficiencies the site is considered to be good but not excellent. The soil material is a very heavy calcareous clay.

*Ankara (City) Weather Station

TOKYO, JAPAN

Latitude: 35°41'N **Longitude:** 139°46'E (Weather Station)

	SITE A	SITE B
1958 Date of Sampling:	February	February
Sampled Area (Sq. Feet):	1.34	1.34
Depth Sampled (Inches):	0-7	0-7
Total Air-dried Weight of Sample (Lbs.):	26.5	27.0
Beltsville Numbers:	58184	58185
1958 d/m Sr 90/Kg of soil:	273.50 266.52	204.52 224.38
mc Sr 90/mi^2:	30.82 30.03	23.47 25.76
Average:	30.4	24.6
Previous Sampling:	4/4/56	2/10/55 4/4/56

Total Precipitation* (Inches)

1953	59.28
1954	69.81
1955	60.45
1956	66.85
1957	58.70
1958 Jan.-Feb.	5.39
Total	320.48

Site A: This site is in the rear lawn of a residence in Tokyo. The lawn has a good grass cover. The soil has adequate clay content for holding strontium 90. There is some threat to the future sampling due to desire of the occupants for an excellent grass cover with a threat of digging and re-seeding. As sampled in 1958, the site is considered excellent.

Site B: This site is on a narrow flat terrace in a garden between a walk and the edge of the steep bank of the terrace. The lawn grass sod is excellent and the soil has capacity to hold the strontium 90. There is a small amount of sheltering by trees. The site as sampled in 1958 is considered good.

*Tokyo (city) Weather Station

BEIRUT, LEBANON

Latitude: 33°49'N Longitude: 35°29'E (Khalde Airport)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	48.0
Beltsville Number:	58221
1958 d/m Sr 90/Kg of soil:	150.02 147.44
mc Sr 90/mi^2:	30.62 30.09
Average:	30.4
Previous Sampling:	2/10/55 10/1/56

Total Precipitation* (Inches)

1953		43.02
1954		37.50
1955		31.13
1956		26.25
1957		36.76
1958	Jan.-Mar.	16.40
	Total	191.06

This site is in a well-grassed yard near the center of the older part of the city. There is some sheltering by trees and buildings. The soil has enough clay to hold strontium 90 and it has not been disturbed during the period of deposition. The site is rated fair to good.

*Data from American University Beirut observatory in Beirut which is near the sampling site.

FUKUOKA, JAPAN

Latitude: 33°35'N Longitude: 130°23'E (Weather Station)

1958 Date of Sampling:	February
Sampled Area (Sq. Feet):	1.0
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	36.0
Beltsville Number:	58187
1958 d/m Sr 90/Kg of soil:	119.20 123.06
mc Sr 90/mi^2:	24.45 25.24
Average:	24.8
Previous Sampling:	None

Total Precipitation* (Inches)

1953	98.0
1954	86.2
1955	64.6
1956	76.8
1957	74.8
1958 Jan.-Feb.	5.9
Total	406.3

The sampling site is in the front yard of a residence. The soil is sandy but is believed to have satisfactory base holding capacity for the strontium 90. There is more sheltering by trees and shrubs than is desirable. The grass sod is good and the site has not been disturbed. Because of the sheltering the site is considered only good to fair.

*Fukuoka Weather Station

DAMASCUS, UNITED ARAB REPUBLIC

Latitude: 33°29'N Longitude: 36°14'E (Mezze Airport)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	40.5
Beltsville Number:	58220
1958 d/m Sr 90/Kg of soil:	74.68 74.76
mc Sr 90/mi^2:	12.86 12.88
Average:	12.9
Previous Sampling:	2/11/55 10/2/56

Total Precipitation* (Inches)

1953	15.79
1954	9.02
1955	6.85
1956	5.43
1957	9.84
1958 Jan.-March	3.05
Total	49.98

The site is in a well-grassed yard of a residence near the center of the city. There is some sheltering from trees and buildings. The soil has enough clay to hold strontium 90 and it has not been disturbed during the period of deposition. The site is rated fair to good.

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*General Monthly Bulletin of Current Statistics
Statistical Abstracts of Syria, 1956 and 1957

HAMILTON, BERMUDA

Latitude: 32°18'N Longitude: 64°46'W

1958 Date of Sampling:	August
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches)	0-6
Total Air-dried Weight of Sample (Lbs.):	41.5
Beltsville Number:	58966
1958 d/m Sr 90/Kg of soil:	234.86
mc Sr 90/mi^2:	41.4
Previous Sampling:	None

Total Precipitation	(Inches)
1953	55.29
1954	51.62
1955	57.36
1956	56.15
1957	77.49
1958 Jan.-Aug.	60.19
Total	358.10

The sample was taken on the grounds of the Botanic Gardens in Hamilton. This sampling area is a well-grassed site and is used for occasional tennis. There is no evident wear on the grass. The soil is a heavy clay and has a tendency to forr small cracks when dry. Because of this, the site is rated as good rather than excellent. The soil has not been disturbed during the period of deposition of strontium 90.

MIAMI, FLORIDA

Latitude: 25°49'N Longitude: 80°17'W (Weather Station)

1958 Date of Sampling:	April
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	34.5
Beltsville Number:	58309
1958 d/m Sr 90/Kg of soil:	128.50
mc Sr 90/mi^2:	18.8
Previous Sampling:	4/1957

Total Precipitation* (Inches)

1953		64.2
1954		61.8
1955		41.6
1956		36.9
1957		70.6
1958	Jan.-April	13.0
	Total:	288.1

The sampling site is on the experimental area of the Campus of the University of Miami in South Miami. The area is made up largely of coral rock. There are no first-class soil conditions for sampling. The spot sampled is a grassed area in front of the water treatment plant. It is near some pine trees but the sheltering is not too bad. The coral rock has been covered by enough soil to permit a good grass sod. It is a bit too shallow to coral rock to be a good site. Because of the shallowness and the sheltering the site is rated as only fair.

*Miami (airport) Weather Station

KARACHI, PAKISTAN

Latitude: 24°48'N Longitude: 66°59'E (Weather Station)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	35.5
Beltsville Number:	58193
1958 d/m Sr 90/Kg of soil:	46.82 45.68
mc Sr 90/mi^2:	7.07 6.89
Average:	7.0
Previous Sampling:	None

Total Precipitation* (Inches)

1953		19.3
1954		6.0
1955		7.5
1956		12.9
1957		1.9
1958	Jan.-March	0.6
	Total:	48.2

The sampling site is in the lawn of a residence in the city of Karachi. The soil is covered by a good grass sod and has not been disturbed during the period of strontium 90 deposition. The area is unsheltered. As a site this sampling spot is rated as excellent. However, complete assurance could not be obtained that filtered water is always used for watering the grass. If unfiltered water has been used on occasion the strontium 90 found might be somewhat high.

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*Manora Weather Station, Karachi

CALCUTTA, INDIA

Latitude: 22°32'N Longitude: 88°20'E (Weather Station)

1958 Date of Sampling:	February
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	45.0
Beltsville Number:	58192
1958 d/m Sr 90/Kg of soil:	79.72 75.04
mc Sr 90/mi^2:	15.25 14.35
Average:	14.8
Previous Sampling:	None

Total Precipitation* (Inches)

1953	49.29
1954	47.70
1955	54.5
1956	68.9
1957	50.8
1958 Jan.-Feb.	3.15
Total:	274.34

The sampling site in the city of Calcutta is in a vacant grassed lot. Cattle keep the vegetation close cropped. There is an undesirable amount of micro relief to the surface of the soil. The soil is underlain by gravel. In places this comes close to the surface and sampling is difficult. There is no sheltering of the site. The sample and site is considered good.

*Alipore Weather Station, Calcutta

KAHUKU, OAHU, HAWAII

Latitude: 21°41'N Longitude: 157°57'W

1958 Date of Sampling:		February
Sampled Area (Sq. Feet)		1.34
Depth Sampled (Inches):	a.	0-2
	b.	2-6
Total Air-dried Weight of Sample (Lbs.):	a.	9.5
	b.	36.0
Beltsville Numbers:		58177
		58178
1958 d/m Sr 90/Kg of soil:	a.	443.92
	a.	452.42
	b.	35.69
	b.	35.71
mc Sr 90/mi^2:	a.	17.93
	a.	18.28
	b.	5.46
	b.	5.47
	Total:	23.6
Previous Sampling:		11/23/55

Total Precipitation* (Inches)

1953		23.51
1954		50.31
1955		42.86
1956		53.16
1957		48.21
1958	Jan.-Feb.	8.98**
	Total	227.03

This sample was taken on the Kahuku Golf Course which is near the ocean. The soil material is coral sand. There is a good grass sod with no sheltering by trees. In this position with respect to the ocean and rising elevation inland, precipitation may change very rapidly. Hence, a close correspondence between the rain gauge and the sampling site cannot be absolutely certain. The site is rated as good.

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*Kahuku Station No. 912
**January-February mean, Climate and Man

WAHIAWA, OAHU, HAWAII (Mauka Intake)

Latitude: 21°30'N **Longitude:** 157°55'W

1958 Date of Sampling:		May
Sampled Area (Sq. Feet):	a.	1.10
	b.	0.50
Depth Sampled (Inches):	a.	0-2
	b.	2-6
Total Air-dried Weight of Sample (Lbs.)	a.	5.0
	b.	7.5
Beltsville Numbers:		58383
		58384
1958 d/m Sr 90/Kg of soil:	a.	1910.46
	b.	345.90
mc Sr 90/mi^2:	a.	49.49
	b.	29.57
	Total:	79.1
Previous Sampling:		None

Total Precipitation* (Inches)

1953	160.15
1954	253.04
1955	183.92**
1956	200.00
1957	162.00
1958 Jan.-May	47.00***
Total	1006.11

This site is near the rain gauge. The soil is largely organic matter. The area is level and has not been disturbed.

*Station No. 882, Wahiawa Mauka Intake
**December 1955 included in 1956 total.
***Estimated 12.00 inches for May 1958 since only a combined figure of 23.85 inches for May and June is available.

OAHU, HAWAII (Leilehua Golf Course)

Latitude: 21°29'N Longitude: 158°04'W

1958 Date of Sampling:		February
Sampled Area (Sq. Feet):		1.34
Depth Sampled (Inches):	a.	0-2
	b.	2-6
Total Air-dried Weight of Sample (Lbs.):	a.	10.5
	b.	39.0
Beltsville Numbers:		58175
		58176
1958 d/m Sr 90/Kg of soil:	a.	493.47
	a.	498.00
	b.	69.42
	b.	63.68
mc Sr 90/mi^2:	a.	22.04
	a.	22.24
	b.	11.51
	b.	10.56
	Total:	33.2
Previous Sampling:		11/23/55
		11/6/57

Total Precipitation* (Inches)

1953	32.36
1954	63.47
1955	74.84
1956	58.42
1957	62.32
1958 Jan.-Feb.	11.62
Total	303.03

This sampling site is on the golf course across the road from the airport near Schofield Barracks. The heavy clay soil has a grass sod. The area has not been disturbed during the period of deposition of strontium 90. There is very little tendency to crack when dry. There is no sheltering due to trees. This site is rated as good to excellent. The rain gauge is not at the exact sampling site.

* Station No. 872, Wahiawa
**January-February mean, Climate and Man.

OAHU, HAWAII (Kawailoa Girls' School)

Latitude: 21°22'N Longitude: 157°45'W

1958 Date of Sampling:		February
Sampled Area (Sq. Feet):		1.34
Depth Sampled (Inches):	a.	0-2
	b.	2-6
Total Air-dried Weight of Sample (Lbs.):	a.	10.5
	b.	29.5
Beltsville Numbers:		58179
		58180
1958 d/m Sr 90/Kg of soil:	a.	473.72
	a.	508.20
	b.	79.96
	b.	78.42
mc Sr 90/mi^2:	a.	21.15
	a.	22.69
	b.	10.03
	b.	9.84
	Total:	31.9
Previous Sampling:		11/23/55
		11/6/57

Total Precipitation* (Inches)

1953		33.50
1954		71.01
1955		85.24
1956		69.79
1957		62.73
1958	Jan.-Feb.	11.62***
	Total	333.89

The sampling area here is in the lawn of the Girls' School. There is a heavy grass sod with no tendency for soil cracking in dry weather. There are no absolutely level areas but it is not believed that there would be any surface movement of water except in exceedingly heavy downpours. The site is rated as good to excellent. The rain gauge is not as close to this site as is desirable.

* Station No. 838, Kaneohe Ranch
** Estimated value by Hawaiian authorities.
***January-February mean for Wahiawa Station (No. 872), Climate and Man.

WAKE ISLAND

Latitude: 19°17'N Longitude: 166°39'E (Weather Station)

1958 Date of Sampling:	February
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	44.5
Beltsville Number:	58183
1958 d/m Sr 90/Kg of soil:	103.28 110.66
mc Sr 90/mi^2:	19.54 20.94
Average:	20.2
Previous Sampling:	4/2/56

Total Precipitation* (Inches)

1953	37.20
1954	42.23
1955	32.62
1956	30.16
1957	29.65
1958 Jan.-Feb.	1.18
Total:	173.04

This site was very good in 1956 and quite satisfactory in 1958. It is doubtful that any further usefull samplings can be done due to the activity of rodents in these remnants of garden plots. The vegetation has been annual weeds. The soil was brought in from Japan to make small garden plots. During the dry season the soil is incoherent and very difficult to sample with precision.

*Wake Island Weather Station

SAN JUAN, PUERTO RICO

Latitude: 18°28'N Longitude: 66°07'W (Weather Station)

1958 Date of Sampling:	November
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-7
Total Air-dried Weight of Sample (Lbs.):	67.5
Beltsville Number:	5985
1958 d/m Sr 90/Kg of soil:	118 103
mc Sr 90/mi^2:	33.87 29.57
Average:	31.7
Previous Sampling:	None

Total Precipitation* (Inches)

1953		48.1
1954		59.5
1955		59.9
1956		70.1
1957		52.8
1958	Jan.-Nov.	69.6
	Total	360.0

This site is located at the airport in a level, well grassed area. The soil has enough clay to hold strontium 90 and it has not been disturbed during the period of deposition. There is no sheltering from trees or buildings but there is infrequent flooding. The site is rated good to excellent. The site may have been covered by a few inches of water for a short period of time during one hurricane in the period of deposition of strontium 90.

*San Juan (airport) Weather Station. Later data are from new Isla Verde Airport (18°26'N, 66°00'W).

DAKAR, SENEGAL

Latitude: 14°44'N Longitude: 17°30'W (Weather Station)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-4
Total Air-dried Weight of Sample (Lbs.):	55.5
Beltsville Number:	58217
1958 d/m Sr 90/Kg of soil:	26.54
mc Sr 90/mi^2:	6.3
Previous Sampling:	9/10/56

Total Precipitation* (Inches)

1953	16.42
1954	29.29
1955	26.17
1956	18.54
1957	23.83
1958 Jan.-Mar.	0.02
Total:	114.27

This site is at the grassed end of a series of garden plots near the airport. The soil is a clay derived from basalt. It has too much tendency to crack to be a first class site. It should be rated as fair. If there is any loss downward in the cracks to a depth below sampling this would lower the value for strontium 90 found. It is not thought that this has occurred at the time of last sampling. The site is 140 yards inland from the Atlantic Ocean.

*Yoff Airport Weather Station, Dakar

HANN, SENEGAL

Latitude: 14°44'N Longitude: 17°30'W (Yoff Airport, Dakar)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	53.2
Beltsville Number:	58218
1958 d/m Sr 90/Kg of soil:	11.68
mc Sr 90/mi^2:	2.6
Previous Sampling:	None

Total Precipitation* (Inches)

1953	16.42
1954	29.29
1955	26.17
1956	18.54
1957	23.83
1958 Jan.-Mar.	0.02
Total:	114.27

The site here is on the grounds of the Experiment Station. The area was said to have been undisturbed for a number of years. The vegetative cover is good sod of coarse lawn grass. It is watered to keep the grass growing. The soil material is a coarse, clean sand. It is possible that some strontium 90 has been leached below sampling depth. Because of the lack of clay in the soil this site cannot be considered first class. Sampling in the general area of Hann and Dakar is difficult. The sandy soils blow during dry weather and the clay soils tend to crack. These are the principal kinds of soil textures found here.

*Rainfall data are for airport at Dakar. Their applicability to Hann is open to question.

MANILA
(Downtown Site)

Latitude: 14°35'N Longitude: 120°59'E (Maraman Building Weather Station)

1958 Date of Sampling:	February
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	37.0
Beltsville Number:	58189
1958 d/m Sr 90/Kg of soil:	45.16 40.06
mc Sr 90/mi^2:	7.10 6.30
Average:	6.7
Previous Sampling:	None

Total Precipitation* (Inches)

1953	95.12
1954	71.64
1955	50.62
1956	86.97
1957	49.74
1958 Jan.-Feb.	0.59
Total:	354.68

This site has a medium textured soil that has enough clay to hold strontium 90 but does not form shrinkage cracks. The land was made by hauling in material to make a good lawn. It has not been disturbed during the time of deposition of strontium 90. The grass cover is excellent. Watering is with filtered city water. This site is rated as excellent.

*Data taken from 3 stations: Maraman Building (in downtown Manila), Nichols Field, and International Airport. No complete data available from any one station.

MANILA
(McKinley Cemetery)

Latitude: 14°35'N Longitude: 120°59'E (Marsman Building Weather Station)

1958 Date of Sampling:		February
Sampled Area (Sq. Feet):		1.34
Depth Sampled (Inches):		0-6
Total Air-dried Weight of Sample (Lbs.):		50.5
Beltsville Number:		58188
1958 d/m Sr 90/Kg of soil:		43.04 38.98
mc Sr 90/mi^2:		9.24 8.37
	Average:	8.8
Previous Sampling:		4/9/56

Total Precipitation* (Inches)

1953	95.12
1954	71.64
1955	50.62
1956	86.97
1957	49.74
1958 Jan.-Feb.	0.59
Total:	354.68

This site is at the edge of the cemetery. The ground is covered with a sod of grass but there is some cracking during dry weather. The soil is a heavy clay derived from basalt. Because of the cracking the site is rated as fair. It is not thought that the values for strontium 90 are in appreciable error because of the cracking. The downtown site is rated as a better one.

*Data taken from 3 stations: Marsman Building (in downtown Manile), Nichols Field, and International Airport. No complete data available from any one station.

ADEN

Latitude: 12°50'N Longitude: 45°01'E (Weather Station)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	0.67
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	24.0
Beltsville Number:	58194
1958 d/m Sr 90/Kg of soil:	14.84 12.80
mc Sr 90/mi^2:	3.03 2.61
Average:	2.8
Previous Sampling:	None

Total Precipitation* (Inches)

1953		3.60
1954		7.19
1955		2.68
1956		0.96
1957		1.18
1958	Jan.-Mar.	1.20
	Total	16.81

This site is in a palm grove. While the sample was taken midway between the palms, there is of necessity some shading from any driving rainstorm. Watering is by flooding of small areas by unfiltered spring water. This site has sandy soil but there is some clay in it. It is rated as relatively excellent for such a dry country but cannot be considered to have the degree of reliability found in grassed areas in higher precipitation belts. One has to consider the possibility of some accretion from desert dust. It is not likely however that the dust would carry much strontium 90 in this case.

*Aden (Airport) Weather Station

Missing values for November 1953 and April-May 1955 are filled in by Climate and Man "monthly averages".

CARACAS, VENEZUELA

Latitude: 10°30'N Longitude: 66°55'W (GFV Station)

1958 Date of Sampling:		February
Sampled Area (Sq. Feet):		1.34
Depth Sampled (Inches):		0-6
Total Air-dried Weight of Sample (Lbs.):		47.0
Beltsville Number:		58204
1958 d/m Sr 90/Kg of soil:		27.84 23.81
mc Sr 90/mi^2:		5.56 4.76
	Average:	5.2
Previous Sampling:		2/2/56

Total Precipitation* (Inches)

1953		33.54
1954		45.82
1955		36.89
1956		26.15
1957		24.63
1958	Jan.-Feb.	0.15
	Total:	167.18

This sampling site is in a residential yard at the edge of the city of Caracas. The spot is well grassed and had not been disturbed at the time of sampling in 1958. It is sheltered from one direction by a building. The available area for sampling is small. The site is rated as good.

*Gran Ferrocarril Vzla. rain gauge, Caracas Railway Station. Missing data for January-April 1954 and November-December 1957 are filled in from the Maracay Weather Station (10°15'N 67°36'W), the closest reporting station with reasonably comparable precipitation records.

FORT CLAYTON, PANAMA CANAL ZONE

Latitude: 9°01'N Longitude: 79°37' W

1958 Date of Sampling:		2/58
Sampled Area (Sq. Feet):		1.34
Depth Sampled (Inches):		0-6
Total Air-dried Weight of Sample (Lbs.):		49.5
Beltsville Number:		58207
1958 d/m Sr 90/Kg of soil:		40.70 44.90
mc Sr 90/mi^2:		8.57 9.45
	Average:	9.0
Previous Sampling:		1/3/56

Total Precipitation* (Inches)

1953	74.53
1954	101.07
1955	88.81
1956	69.40
1957	76.21
1958 Jan.-Feb.	1.56
Total:	411.58

This nearly level sampling site is on the golf course at Fort Clayton. The area is fairly well grassed, not sheltered by trees or buildings and has not been disturbed during the period of deposition of strontium 90. The soil is a heavy clay which cracks fairly severely when dry. The site is rated as good.

*Pedro Miguel rain gauge (Panama Canal Co.)

FORT AMADOR, PANAMA CANAL ZONE

Latitude: 8°58'N Longitude: 79°33'W

1958 Date of Sampling:	2/58
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	51.5
Beltsville Number:	58206
1958 d/m Sr 90/Kg of soil:	30.56 34.38
mc Sr 90/mi^2:	6.69 7.53
Average:	7.1
Previous Sampling:	1/3/56

Total Precipitation* (Inches)

1953		67.71
1954		83.93
1955		84.20
1956		83.21
1957		62.62
1958	Jan.-Feb.	0.93
	Total:	382.60

This sampling site is on the Fort Amador Golf Course. The site is level, well grassed and without sheltering by trees or buildings. There has been no disturbance during the period of deposition of strontium 90. The land is made from calcareous marine sediments brought up during the building of the Canal. The soil is a heavy clay which cracks some when dry. The site is rated excellent.

*Balboa Heights rain gauge (Panama Canal Co.)

BOGOTA, COLOMBIA

Latitude: 4°38'N Longitude: 74°05'W (Weather Station)

1958 Date of Sampling:	2/58
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	30.0
Beltsville Number:	58205
1958 d/m Sr 90/Kg of soil:	38.62 35.54
mc Sr 90/mi^2	4.93 4.53
Average:	4.7
Previous Sampling:	1/6/56

Total Precipitation* (Inches)

1953	40.28
1954	41.90
1955	47.96
1956	39.45
1957	34.19
1958 Jan.-Feb.	4.50
Total:	208.28

This site is in a residential yard in the city of Bogota. There is a good grass sod on a soil derived from volcanic ash. The area has not been disturbed during the period of deposition of strontium 90. There is a small amount of sheltering by trees but the site is considered good.

*January and February 1958 values from norms in Climate and Man National Meteorological Observatory, Ciudad Universitaria, Bogota.

SINGAPORE, MALAYA

Latitude: 01°18'N Longitude 103°53'E (Weather Station)

	SITE A	SITE B
1958 Date of Sampling:	2/58	2/58
Sampled Area (Sq. Feet):	1.34	1.34
Depth Sampled (Inches):	0-6	0-6
Total Air-dried Weight of Sample (Lbs.):	40.0	43.5
Beltsville Number:	58190	58191
1958 d/m Sr 90/Kg of soil:	24.70 23.12	22.88 22.42
mc Sr 90/mi^2	4.20 3.93	4.22 4.15
Average:	4.1	4.2
Previous Sampling:	4/15/56	4/13/56

Total Precipitation* (Inches)

1953	75.33
1954	120.05
1955	88.00
1956	97.02
1957	79.15
1958 Jan.-Feb.	14.36
Total:	473.91

Both sites are in well grassed residential yards in Singapore. The areas have not been disturbed during the period of accumulation of strontium 90. There is no sheltering by trees or buildings. These sites are rated good to excellent.

*Kallang Aerodrome Weather Station, Singapore.
Data for 1956-1958 from new Singapore Airport site (01°21'N 103°54'E).

KIKUYU, KENYA

Latitude: 1°14'S Longitude: 36°38'E (Sample Site)

1958 Date of Sampling:		March
Sampled Area (Sq. Feet):		1.31
Depth Sampled (Inches):		0-5½
Total Air-dried Weight of Sample (Lbs.):		25.5
Beltsville Number:		58195
1958 d/m Sr 90/Kg of soil:		66.76 65.20
mc Sr 90/mi^2:		7.41 7.23
	Average:	7.3
Previous Sampling:		9/27/56

Total Precipitation* (Inches)

1953	22.50
1954	47.40
1955	29.95
1956	28.06
1957	47.77
1958 Jan.-March	9.77
	185.45

This site is in the instrument yard of the Weather Station at the East African Agriculture and Forestry Research Organization at Kikuyu. The heavy clay soil is covered with a very dense Bermuda grass sod. The soil samples are difficult to take because of the high clay content of the soil. The area has not been disturbed during deposition of the strontium 90. This is an excellent site.

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*East African Agriculture and Forestry Research Station, Kikuyu.

BELEM, BRAZIL

Latitude: 1°28'S Longitude: 48°29'W (Belem Airport)

	SITE A	SITE B
1958 Date of Sampling:	3/58	3/58
Sampled Area (Sq. Feet):	1.34	1.34
Depth Sampled (Inches):	0-6	0-6
Total Air-dried Weight of Sample (Lbs.):	44.5	50.5
Beltsville Number:	58215	58216
1958 d/m Sr 90/Kg of soil:	32.98 35.20	33.74 28.26
mc Sr 90/mi^2:	6.24 6.66	7.25 6.07
Average:	6.4	6.7
Previous Sampling:	1/31/56	None

Total Precipitation* (Inches)

1953	109.98
1954	94.54
1955	130.69
1956	93.19
1957	93.19
1958 Jan.-Mar.	42.05
Total:	563.64

These sites are located on well grassed areas which have not been disturbed. The soil is sandy but it is thought to have enough organic matter and clay to hold strontium 90. The area of Site A is small, there is sheltering from buildings so it is rated fair. Site B has no sheltering so it is rated excellent.

*Belem (Airport) Weather Station. Available records are incomplete, so Climate and Man norms are substituted for the following missing values: August 1954; May and September 1955; all of 1956; all of 1957; and March 1958.

CANTON ISLAND

Latitude: 02°46'S Longitude: 171°43'W (Weather Station)

	SITE A	SITE B
1958 Date of Sampling:	February	February
Sampled Area (Sq. Feet):	1.34	1.34
Depth Sampled (Inches):	0-8	0-8
Total Air-dried Weight of Sample (Lbs.):	31.0	48.5
Beltsville Number:	58181	58182
1958 d/m Sr 90/Kg of soil:	37.18 34.02	55.60 54.26
mc Sr 90/mi^2:	4.90 4.48	11.47 11.19
Average:	4.7	11.3
Previous Sampling:	4/27/56	None

Total Precipitation* (Inches)	
1953	35.88
1954	8.27
1955	17.36
1956	16.15
1957	49.68
1958 Jan.-Feb.	26.38
Total:	153.72

Neither site on Canton Island is good. The site sampled in 1956 and again in 1958 is in a small clump of bushes. There are no undisturbed areas that do not have sheltering vegetation. These bushes are on a remnant of guano deposit left from fertilizer gathering operations many years ago. The material is coarse grained coral fragments. There is a reasonable amount of organic matter in the upper few inches. This site is well protected from the ocean but is near the edge of a lagoon. The site can rate as only fair.

The site near the lighthouse is in a small grove of trees. It is only a few yards from the edge of the ocean. It is in a mist from the ocean spray much of the time. The soil material is coral sand and minute sea shells. It is probable that sand from the beach is currently lodging in the grove by wind action. There is no ground vegetation under the small trees. This site can be rated only as poor.

These were the best sites to be found on the island. The land surface is coral rock in nearly all locations.

*Canton Island Weather Station

LEOPOLDVILLE, BELGIAN CONGO

Latitude: 4°20'S Longitude: 15°14'E (Weather Station)

	SITE A	SITE B
1958 Date of Sampling:	March	March
Sampled Area (Sq. Feet):	1.34	1.34
Depth Sampled (Inches):	0-6	0-6
Total Air-dried Weight of Sample (Lbs.):	45.5	33.0
Beltsville Number:	58200	58201
1958 d/m Sr 90/Kg of soil:	30.48 31.76	34.23 35.73
mc Sr 90/mi^2:	5.90 6.15	4.80 5.01
Average:	6.0	4.9
Previous Sampling:	9/12/56	None

Total Precipitation* (Inches)

1953	63.43
1954	54.52
1955	54.06
1956	46.26
1957	60.67
1958 Jan.-March	14.41
Total:	293.35

Site A: The samples at this site were taken in the back yard of a residence in Leopoldville. It is well grassed and level but is subject to some traffic in connection with clothes drying operations. The soil is sandy but it is believed that there is enough organic matter and clay to retain the strontium 90. The site is rated as good.

Site B: This site is in the edge of a large open wooded lawn area in Leopoldville. The site has not been disturbed. There is a thin cover of grass. Some sheltering by trees makes this site only fair.

*Leopoldville - Ouest Weather Station

HUANCAYO, PERU

Latitude: 12°02' S Longitude: 75°13'W (Weather Station)

1958 Date of Sampling:	2/58
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	56.5
Beltsville Number:	58209
1958 d/m Sr 90/Kg of soil:	27.65 25.92
mc Sr 90/mi^2:	6.64 6.23
Average:	6.4
Previous Sampling:	2/9/56

Total Precipitation* (Inches)

1953		29.61
1954		33.47
1955		23.66
1956		29.46
1957		24.01
1958	Jan.-Feb.	11.02
	Total:	151.23

This sampling site is on the grounds of the Institute Geophysico de Huancayo. The sample was taken inside the meteorological compound. The area is well grassed. This is considered an excellent site.

*Huancayo Weather Station

LIMA, PERU

Latitude: 12°06'S Longitude: 77°01'W (Weather Station)

1958 Date of Sampling:	2/58
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	42.0
Beltsville Number:	58208
1958 d/m Sr 90/Kg of soil:	12.16 12.14
mc Sr 90/mi^2:	2.17 2.17
Average:	2.2
Previous Sampling:	1/9/56

Total Precipitation* (Inches)

1953		2.78
1954		1.57
1955		2.37
1956		1.26
1957		1.41
1958	Jan.-Feb.	0.22
	Total	9.61

Both the 1956 and the 1958 samples were taken in a residential yard in Lima. The area sampled in 1956 was dug up during the period 1956-1958. Another site was located in the yard that was supposed not to have been disturbed during the period of strontium 90 deposition. There is doubt that this is true since there was no one who really knew. The sample can be rated as good in 1956 but no better than of doubtful value in 1958.

*Limatambo Weather Station

KATHERINE, AUSTRALIA

Latitude: 14°18'S Longitude: 132°18'E (Weather Station)

1958 Date of Sampling:	3/58
Sampled Area (Sq. Feet):	1.36
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	67.5
Beltsville Number:	58313
1958 d/m Sr 90/Kg of soil:	15.40 17.26
mc Sr 90/mi^2:	4.36 4.88
Average	4.6
Previous Sampling:	3/57

Total Precipitation* (Inches)

1953	39.54
1954	43.06
1955	31.40
1956	39.48
1957	54.85
1958 Jan.-Mar.	13.92
Total:	222.25

This sampling site is at the Agricultural Experiment Station at Katherine. The samples were taken by the Australian Commonwealth Scientific Industrial Research Organization Staff.

*Katherine Weather Station

SALISBURY, SOUTHERN RHODESIA

Latitude: 17°50'S Longitude: 31°01'E (Weather Station)

	SITE A	SITE B
1958 Date of Sampling:	3/58	3/58
Sampled Area (Sq. Feet):	1.34	1.34
Depth Sampled (Inches):	0-6	0-6
Total Air-dried Weight of Sample (Lbs.):	49.0	52.0
Beltsville Number:	58196	58197
1958 d/m Sr 90/Kg of soil:	24.16 23.24	23.68 20.56
mc Sr 90/mi^2:	5.04 4.24	5.24 4.55
Average:	4.9	4.9
Previous Sampling:	9/17/56	None

Total Precipitation* (Inches)

1953	30.69
1954	40.78
1955	32.21
1956	45.79
1957	34.43
1958 Jan.-Mar.	16.54
Total:	200.44

One sample was taken on the grounds of the Agricultural Experiment Station in the edge of Salisbury. This is an area of virgin bunch grass. The soil is heavy but cracking is not bad.

The other site is in the Botanic Garden also in the edge of Salisbury. This is a grassed lawn area. Both sites are considered good to excellent.

*Belvedere Weather Station, Salisbury

ANTOFAGASTA, CHILE

Latitude: 23°26'S **Longitude:** 70°28'W (Weather Station)

1958 Date of Sampling:	**February**
Sampled Area (Sq. Feet):	81.0
Depth Sampled (Inches):	0-½
Total Air-dried Weight of Sample (Lbs.):	135.0
Beltsville Number:	58210
1958 d/m Sr 90/Kg of soil:	39.10 38.82
mc Sr 90/mi^2:	0.37 0.37
Average:	0.4
Previous Sampling:	1/13/56

Total Precipitation* (Inches)

1953	0.0
1954	0.0
1955	0.0
1956	0.0
1957	0.0
1958 Jan.	0.0
Total	0.0

This sampling site is in the bare desert a few kilometers from the city of Antofagasta. This position is sheltered from winds by mountains. It is as good a site as can be found in an area devoid of plant life. There is a desert pavement of small pebbles. Tracks stay for a long time indicating not too much movement of material by the wind. The site is rated as good in this situation.

*Antofagasta Weather Station

SAO PAULO, BRAZIL

Latitude: 23°33'S Longitude: 46°38'W (Sao Paulo Airport)

1958 Date of Sampling:	February
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	42.5
Beltsville Number:	58214
1958 d/m Sr 90/Kg of soil:	34.06 35.53
mc Sr 90/mi^2:	6.16 6.42
Average:	6.3
Previous Sampling:	1/30/56

Total Precipitation* (Inches)		
1953		48.94
1954		65.04
1955		50.52
1956		56.02
1957		56.02
1958	Jan.-Feb.	15.35
	Total	291.89

This site is located in a level, well-grassed residential yard about twelve miles south of Sao Paulo. The soil has enough clay to hold strontium 90 and it has not been disturbed during the period of deposition. The area is fairly small and there is sheltering from trees. The site is rated fair.

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*Sao Paulo (airport) Weather Station. The figure for 1953 includes 11 months of record; that for 1954, 11 months of record; that for 1955, 9 months of record. The missing months (Dec. 1953; Apr. 1954; Apr., May, and Dec. 1955) are filled in with monthly norms from Climate and Man. The figures given for 1956 and 1957 are annual norms from the same source.

ALICE SPRINGS, AUSTRALIA

Latitude: 23°48'S Longitude: 133°53'E (Weather Station)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.36
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	40.5
Beltsville Number:	58315
1958 d/m Sr 90/Kg of soil:	15.00 19.92
mc Sr 90/mi^2:	2.55 3.38
Average:	3.0
Previous Sampling:	6/19/56

Total Precipitation* (Inches)

1953	12.74
1954	9.47
1955	9.48
1956	10.84
1957	9.36
1958 Jan.-Mar.	0.33
Total	52.22

This sampling site is at the Australian Agricultural Experiment Station at Alice Springs. The soil sample was taken by the Australian Commonwealth Scientific and Industrial Research Organization staff.

*Alice Springs (city) Weather Station

ASUNCION, PARAGUAY

Latitude: 25°21'S Longitude: 57°37'W (Weather Station)

1958 Date of Sampling:	February
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	62.0
Beltsville Number:	58213
1958 d/m Sr 90/Kg of soil:	29.10 27.60
mc Sr 90/mi^2:	7.67 7.28
Average:	7.5
Previous Sampling:	1/1956

Total Precipitation* (Inches)

1953		64.96
1954		68.05
1955		42.37
1956		64.99
1957		57.33
1958	Jan.-Feb.	10.07
	Total	307.77

The sampling site is on a golf course near Asuncion. The area is well grassed and level. It has not been disturbed during the period of deposition of strontium 90. The soil is sandy but has enough clay to hold strontium 90. The site is rated as excellent.

*Asuncion Weather Station

BRISBANE, AUSTRALIA

Latitude: 27°28'S Longitude: 153°02'E (Weather Station)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.36
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	51.0
Beltsville Number:	58311
1958 d/m Sr 90/Kg of soil:	55.34 53.44
mc Sr 90/mi^2:	11.82 11.42
Average:	11.6
Previous Sampling:	5/8/56

Total Precipitation* (Inches)

1953	43.60
1954	61.36
1955	50.41
1956	59.18
1957	20.59
1958 Jan.-March	14.18
Total	249.32

This sample was collected by the Australian Commonwealth Scientific and Industrial Research Organization staff.

*Brisbane (city) Weather Station

DURBAN, NATAL, UNION OF SOUTH AFRICA

Latitude: 29°50'S Longitude: 31°02'E (Weather Station)

	SITE A	SITE B
1958 Date of Sampling:	March	March
Sampled Area (Sq. Feet):	1.34	1.34
Depth Sampled (Inches):	0-6	0-6
Total Air-dried Weight of Sample (Lbs.):	38.5	55.0
Beltsville Numbers:	58198	58199
1958 d/m Sr 90/Kg of soil:	45.82 38.88	26.65 32.44
mc Sr 90/mi^2:	7.50 6.36	6.23 7.58
Average:	6.9	6.9
Previous Sampling:	9/14/56	9/14/56

Total Precipitation* (Inches)

1953	44.16
1954	34.25
1955	36.49
1956	55.93
1957	43.48
1958 Jan.-March	25.20
Total	239.51

Site A: This site is in a residential lawn. It is a small level unsheltered area, well-grassed and has not been disturbed during the deposition period of strontium 90. The site is rated as good to excellent as sampled in 1956 and in 1958.

Site B: The Natal University site is on a level spot on the University Campus. The cover is a very dense sod of tall grass that makes sampling a bit difficult. There is no sheltering by trees or buildings. The site is considered excellent.

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*Durban (city) Weather Office. Later data are from the new airport site (29°58'S 30°57'E), and some earlier data may be from the old airport site (29°51"S 31°03'E).
The 1957 figure includes 9 months of record, and the Climate and Man norms for April-June.

PERTH, AUSTRALIA

Latitude: 31°57'S Longitude: 115°49'E (Weather Station)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.36
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	64.0
Beltsville Number:	58314
1958 d/m Sr 90/Kg of soil:	19.22 15.99
mc Sr 90/mi^2:	5.15 4.29
Average:	4.7
Previous Sampling:	5/1956

Total Precipitation* (Inches)

1953	37.14
1954	28.05
1955	46.52
1956	37.35
1957	33.40
1958 Jan.-Mar.*	0.29
Total:	182.75

This sample was taken by the Australian Commonwealth Scientific and Industrial Research Organization staff.

*Perth (city) Weather Station

SANTIAGO, CHILE

Latitude: 33°27'S **Longitude:** 70°42'W **(Weather Station)**

1958 Date of Sampling:	**February**
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	51.5
Beltsville Number:	58211
1958 d/m Sr 90/Kg of soil:	23.58 22.71
mc Sr 90/mi^2:	5.16 4.97
Average:	5.1
Previous Sampling:	1/16/56

Total Precipitation* (Inches)	
1953	23.40
1954	12.13
1955	7.02
1956	9.95
1957	12.10
1958 Jan.-Feb.	0.00
Total:	64.60

This site is in uncultivated land that is used for grazing and bird hunting. The cover is annual plants. Nothing grows during the dry season. It is not thought that there is appreciable blowing during the dry season when there is no live cover. The soil is derived from material containing a large component of volcanic ash. The site is rated as good.

*Santiago (city) Weather Station, which is about 14 miles due east of the soil sample site.
The 1956 value includes 11 months of record and the Climate and Man norm for December.

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BUENOS AIRES, ARGENTINA

Latitude: 34°35'S Longitude: 58°29'W (Weather Station)

1958 Date of Sampling:	February
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	49.5
Beltsville Number:	58212
1958 d/m Sr 90/Kg of soil:	50.82 55.64
mc Sr 90/mi^2:	10.70 11.71
Average:	11.2
Previous Sampling:	1/18/56

Total Precipitation* (Inches)

1953		49.92
1954		36.66
1955		34.71
1956		32.76
1957		31.20
1958	Jan.-Feb.	12.20
	Total:	197.45

The sampling site is in a small garden area in the city of Buenos Aires. It is level and well grassed. The soil has the capacity to hold strontium 90. This site is rated as good.

*Central Buenos Aires Weather Station

ADELAIDE, AUSTRALIA

Latitude: 34°56'S Longitude: 138°35'E (Weather Station)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.36
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	66.5
Beltsville Number:	58312
1958 d/m Sr 90/Kg of soil:	42.59 41.64
mc Sr 90/mi^2:	11.86 11.60
Average:	11.7
Previous Sampling:	5/7/56

Total Precipitation* (Inches)

1953		20.00
1954		16.73
1955		24.58
1956		27.24
1957		16.71
1958	Jan.-Mar.	1.49
	Total:	106.75

This sample was collected by the Australian Commonwealth Scientific and Industrial Research Organization staff.

*Adelaide (city) Weather Station

NORTH AUCKLAND, NEW ZEALAND

Latitude: 35°43'S Longitude: 174°12'E (Sample Site)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.00
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	29.5
Beltsville Number:	58320
1958 d/m Sr 90/Kg of soil:	39.26 36.72
mc Sr 90/mi^2 :	6.60 6.17
Average:	6.4
Previous Sampling:	1/18/54 5/10/56

Total Precipitation* (Inches)

1953	60.94
1954	69.25
1955	74.84
1956	97.40
1957	54.91
1958 Jan.-Mar.	17.10
Total:	374.44

This sample was collected by the New Zealand Department of Scientific and Industrial Research.

*Maungatapere Weather Station, which is directly south of the soil sample site by 2' latitude.

WELLINGTON, NEW ZEALAND

Latitude: 41°17'S Longitude: 174°46'E (Weather Station)

1958 Date of Sampling:		March
Sampled Area (Sq. Feet):		1.03
Depth Sampled (Inches):		0-6
Total Air-dried Weight of Sample (Lbs.):		32.5
Beltsville Number:		58321
1958 d/m Sr 90/Kg of soil:		53.22 55.18
mc Sr 90/mi^2:		9.57 9.92
	Average:	9.7
Previous Sampling:		12/11/53 4/24/56

Total Precipitation* (Inches)

1953		57.33
1954		48.36
1955		57.72
1956		61.23
1957		49.18
1958	Jan.-March	15.35
	Total:	289.17

This sample was collected by the New Zealand Department of Scientific and Industrial Research.

*Wellington (City) Weather Station which is about 17 miles southwest of soil sample site (near Judgeford).

HOBART, TASMANIA

Latitude: 42°53'S Longitude: 147°20'E (Weather Station)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.36
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	43.0
Beltsville Number:	58316
1958 d/m Sr 90/Kg of soil:	56.50 67.08
mc Sr 90/mi^2:	10.18 12.08
Average:	11.1
Previous Sampling:	5/6/56

Total Precipitation* (Inches)

1953		30.16
1954		27.20
1955		22.32
1956		36.68
1957		28.66
1958	Jan.-Mar.	4.21
	Total:	149.23

This sample was taken by the Australian Commonwealth Scientific and Industrial Research Organization.

*Hobart (City) Weather Station

SOUTH CANTERBURY, NEW ZEALAND

Latitude: 44°23'S Longitude: 171°06'E

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	0.98
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	44.0
Beltsville Number:	58319
1958 d/m Sr 90/Kg of soil:	32.16 30.48
mc Sr 90/mi^2:	8.23 7.80
Average:	8.0
Previous Sampling:	1/18/54 4/27/56

Total Precipitation* (Inches)

1953	23.99
1954	21.56
1955	16.70
1956	22.13
1957	28.62
1958 Jan.-Mar.	8.68
Total:	121.68

This sample was collected by the New Zealand Department of Scientific and Industrial Research.

*Adair Weather Station, which is south and east of the soil sample site by 3' latitude and 4' longitude.

PUNTA ARENAS, CHILE (110 km. north)

Latitude: 53°10'S Longitude: 70°54'W (Weather Station)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.34
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	37.0
Beltsville Number:	58310
1958 d/m Sr 90/Kg of soil:	29.66 33.36
mc Sr 90/mi^2:	4.67 5.25
Average:	5.0
Previous Sampling:	1/23/56

Total Precipitation* (Inches)		
1953		14.82
1954		13.65
1955		19.89
1956		22.86
1957		21.47
1958	Jan.-Mar.	5.12
	Total:	97.81

This site is located in a broad right of way through sheep ranch territory. The area is virgin grass sod. There is adequate clay and organic matter for holding strontium. Precise sampling is hampered a little bit by the small gravel in the soil. This is not serious. The site is considered good to excellent.

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*Punta Arenas Weather Station, which is about 110 km. south of the soil sample site. Precipitation at the site is thought to be lower than at the Weather Station.
The 1956 value includes 10 months of record and the Climate and Man norms for February and December.

CAMPBELL ISLAND

Latitude: 52°32'S Longitude: 168°59' (Sample Site)

1958 Date of Sampling:	March
Sampled Area (Sq. Feet):	1.00
Depth Sampled (Inches):	0-6
Total Air-dried Weight of Sample (Lbs.):	8.5
Beltsville Number:	58473
1958 d/m Sr 90/Kg of soil:	274.04
mc Sr 90/mi^2:	13.3
Previous Sampling:	7/1956

Total Precipitation* (Inches)

1953	56.55
1954	64.74
1955	55.38
1956	50.31
1957	61.32
1958 Jan.-Mar.	16.35
Total:	304.65

The sample was collected by the New Zealand Weather Bureau.

*Campbell Island Weather Station, which is also the soil sample site.

DATA ON THE DEPOSITION OF STRONTIUM-90 DURING 1958

(See Addendum, p. 471)

by

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April 20, 1959

Health and Safety Laboratory
UNITED STATES ATOMIC ENERGY COMMISSION
New York, N. Y.

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This report summarizes the data available from the Health and Safety Laboratory on the deposition of Strontium-90 during 1958. The data thus serve to bring up to date HASL-42, "Environmental Contamination from Weapons Tests", which included data through the end of 1957.

This report includes not only information developed at the Health and Safety Laboratory but analyses performed by analytical contractors. A considerable amount of the information will be made part of other reports submitted to the Joint Committee for their consideration.

Some of the analyses reported here were completed after the issuance of the last quarterly supplement to HASL-42 and will not be otherwise published until the next supplement. The policy on data publication has been to include all material available at the time of preparation of these quarterly supplements, or a report such as the present one.

The deposition of Strontium-90 may be described in two ways: one is the rate of fallout, usually on the basis of monthly collections and the other is the cumulative deposition based on soil analyses. These two methods are considered supplementary since none of the monthly pot collections were started early enough to allow valid estimates of the accumulated deposit. On the other hand, difficulties in the sampling and analysis of soils prevent use of soil data for short term rate measurements.

Monthly Collection Networks

Monthly collections of fallout have been made for a period of several years using stainless steel pots. The network reporting results for 1958 is mapped in Fig. 1. The stations are also listed in Table I.

In order to expand the collecting network, an improved device consisting of a plastic funnel and ion exchange column has been developed. Through the cooperation of Dr. Lester Machta of the U. S. Weather Bureau, an additional 22 sites were put into operation in February of 1959. These are shown superimposed on the pot network in Fig. 2, and listed in Table 2. Negotiations are under way to further expand the funnel network outside the United States and to substitute funnels for existing pots.

Precipitation Collections

Collection and analysis of individual rainfalls or other precipitations have been made at three sites. The first of these stations has been in operation since 1955 at Pittsburgh, Pa., and two others in Westwood, N. J., and Richmond, Cal., were initiated in 1958. The available data from these three stations for 1958 are listed in Tables 4, 5, and 6.

The results of these analyses have been subject to numerous interpretations and no additional interpretation will be attempted here.

Soil Analyses

Two sets of data are available on the Strontium-90 content of soils. The first network includes 17 sites in the United States where sampling and analysis have been carried out by HASL personnel. These sites have been sampled annually in October and results for 1955, 1956, and 1957 were included in HASL-42. The locations are shown in Fig. 3 and those analyses available at this time for 1958 samples are listed in Table 7. Additional results should be ready before the Congressional Hearings and will be listed in an addendum to be furnished about the first of May.

The second is a series of samples collected by Dr. Lyle T. Alexander of the U. S. Department of Agriculture at selected sites throughout the world. These samples have been analyzed at the Health and Safety Laboratory and the results of the two most recent collections are mapped in Figs. 4 and 5. The interpretation of these results will be presented in a separate report by Dr. Alexander.

In any program that depends heavily on the quality of chemical analysis, it is desirable to know the reliability of the analytical data. As a test of quality, samples have been submitted to the HASL analysts by Dr. Alexander, identified only by the sample number. A considerable group of these were submitted as blind duplicates and form a good

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check on reproducibility of samples where the identity is not known. Table 8 lists a series of results of such tests.

Summary of Pot Data

The interpretation of fallout data has always been complicated by the introduction of fresh fission products into the atmosphere. This has prevented clean-cut separation of debris from individual tests or even series of tests.

Three major test series have been reported for 1958, the U.S.S.R. series in the spring and fall and the U.S. series in the summer. As a typical example of the data in Table 3, the complete results for the HASL pot station in New York City are plotted in Fig. 6. This figure indicates an increased rate of fallout during 1958 compared to previous years.

The high variability of all fallout sampling and analysis requires smoothing by grouping of data. As an example of the patterns produced by such smoothing, Fig. 7 summarizes the Strontium-90 pot data for 1958 grouped by quarter of the year and by 20° latitude bands. The four quarters consistently show a maximum in the 30-50°N band and a minimum in the equatorial region. It should be noted that the numbers of stations in the five bands are 11, 9, 2, 8, and 6. Therefore, the equatorial region may be less reliable than the other four bands. The southern hemisphere maximum is in the 10-30°S band rather than the most

southerly, and unfortunately stations are not available above 50° in either hemisphere.

In the latitude bands measured, the total Strontium-90 fallout for 1958 would be estimated as 0.76 megacuries. Because of the heavy injections during 1958, it is not possible to use this as a measure of stratospheric depletion. If an extended period free of tests continues, such rates should be readily determined. It should be pointed out, however, that the rate found would not necessarily reflect past rates. The stratospheric depletion rate is not a basic physical constant, but may be a function of the characteristics of the tests producing the stratospheric burden.

It is possible to roughly estimate the age of fission products by the use of isotopic ratios such as the Sr^{89}/Sr^{90} or Ba^{140}/Sr^{90} because of the difference in yields and half-lives. The Ba^{140}/Sr^{90} ratio is only valuable for fairly fresh debris and is measured in precipitation samples. The Sr^{89}/Sr^{90} ratio has been calculated for the pot stations in Table 3, and the grouped data are plotted in Fig. 7.

The most obvious features are,

1. None of the differences between bands are extremely marked.
2. The average age of the debris is greater in the southern hemisphere.
3. After the U.S. summer tests, the average age of the debris is lowest in the equatorial band.

Tungsten Data

During the U.S. summer tests in the Pacific, Tungsten-185 was produced. This nuclide has a half-life of 74 days and furnishes a tracer for this particular test series. The available analyses of pot samples are included in Table 3.

In order to compare total Tungsten-185 fallout at various times, the activity has been extrapolated back to an arbitrary date, June 1, 1958. This also allows addition of results for several months on a sound basis. These extrapolated values, grouped by latitude band for the months available, are shown in Table 9.

For the months (September, October, November) when all bands have data, the totals indicate low Tungsten-185 fallout in the equatorial and the 10-30°S bands, about one-fourth to one-third of that found in the other three bands.

In addition, the data indicate the extrapolated Tungsten-185 fallout to be approximately equal for each of the five months. This is perhaps surprising and may be an artificial indication caused by the grouping.

The total Tungsten-185 deposition, extrapolated to June 1, 1958, may be estimated as 18 megacuries between 50°N and 50°S. By January 1, 1959, this would have decayed to about 2.5 megacuries.

The mean monthly W^{185}/Sr^{90} ratios are listed in Table 10. Considering the same three months as above, it is notable that,

1. The southernmost band shows a markedly lower ratio than the other bands.
2. The maximum ratio appears in the equatorial band.
3. In the three northernmost bands, two peaks appear, in September and November.

The end of this period should represent stratospheric fallout, as tropospheric material should be very low by October and November. Interpretation of the data and the indications noted is largely a meteorological problem and will not be attempted here.

Table I

LIST OF POT STATIONS ACTIVE DURING 1958

United States

Birmingham, Alabama
Richmond, California
W. Los Angeles, California
Coral Gables, Florida
AEC Lab, Coconut Island, Oahu, Hawaii
Gartley Hall, University of Hawaii, Oahu, Hawaii
Lemont, Illinois
Louisville, Kentucky
Westwood, New Jersey
New York, New York
Tulsa, Oklahoma
Pittsburgh, Pennsylvania
Vermillion, South Dakota
Houston, Texas
Salt Lake City, Utah
Seattle, Washington

Australia

Adelaide
Brisbane
Darwin
Melbourne
Perth
Sydney
Townsville

Austria

Klagenfurt
Vienna

Brazil

Italci, State of Sao Paulo
Nova Friburgo, State of Rio
Sao Jose dos Campos, State of Sao Paulo

Chile

Santiago

Colombia

Bogota

Table I (Contd.)

Japan

Hiroshima
Nagasaki

Kenya

Kikuyu

Pakistan

Karachi

Senegal

Dakar

Southern Rhodesia

Salisbury

Taiwan

Tainan
Taipei
Taitung

Tasmania

Hobart

Thailand

Bangkok

Union of South Africa

Durban
Pretoria

Table 2

LIST OF FUNNEL STATIONS STARTED IN FEBRUARY 1959

United States

Anchorage, Alaska
Barrow, Alaska
Cold Bay, Alaska
Juneau, Alaska
San Francisco, California
Denver, Colorado
Hilo, Hawaii
Mauna Loa, Hawaii
International Falls, Minnesota
Columbia, Missouri
Helena, Montana
Williston, North Dakota
Medford, Oregon
Columbia, South Carolina
Dallas, Texas
El Paso, Texas
Houston, Texas
Green Bay, Wisconsin
Silver Hill, Maryland

Outside United States

Canton Island
Truk
Wake

Table 3

POT ANALYSES 1958

United States Sites

Alabama, Birmingham
California, Richmond
California, West Los Angeles
Florida, Coral Gables
Hawaii, Oahu, AEC Lab, Coconut Island
Hawaii, Oahu, Gartley Hall, University of Hawaii
Hawaii, Oahu, Weather Station, Coconut Island
Illinois, Lemont
Kentucky, Louisville
New Jersey, Westwood
New York, New York
Oklahoma, Tulsa
Pennsylvania, Pittsburgh
South Dakota, Vermillion
Texas, Houston
Utah, Salt Lake City
Washington, Seattle

Outside United States Sites

Australia, Adelaide
Australia, Brisbane
Australia, Darwin
Australia, Melbourne
Australia, Perth
Australia, Sydney
Australia, Townsville
Austria, Kalgenfurt
Austria, Vienna
Brazil, Italci, State of Sao Paulo
Brazil, Nova Friburgo, State of Rio
Brazil, Sao Jose dos Campos, State of Sao Paulo
Chile, Santiago
Colombia, Bogota
Japan, Hiroshima
Japan, Nagasaki
Kenya, Kikuyu
Pakistan, Karachi
Senegal, Dakar
Southern Rhodesia, Salisbury
Taiwan, Tainan
Taiwan, Taipei
Taiwan, Taitung
Tasmania, Hobart
Thailand, Bangkok
Union of South Africa, Durban
Union of South Africa, Pretoria

Weather Stations - "Bravo", "Charlie", "Delta", "Echo"

MONTHLY FALLOUT COLLECTIONS

Alabama, Birmingham

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1957 April through December							5.45 ± 0.12	
1958 January	0.66 ± 0.03	11.4 ± 1.4		17			6.11 ± 0.12	3.42
February	0.24 ± 0.01	3.4 ± 0.5		12			6.35 ± 0.13	5.14
March	0.38 ± 0.02	6.4 ± 0.7		16			6.73 ± 0.13	3.03
April	1.67 ± 0.05	24.4 ± 0.18		14			8.40 ± 0.13	3.51
May	1.17 ± 0.05	20.7 ± 0.7		15			9.56 ± 0.14	2.33
June	0.65 ± 0.04	24.5 ± 0.5		38			10.21 ± 0.14	3.10
July	2.11 ± 0.02	88.77 ± 0.11		42			12.32 ± 0.14	6.79
August	1.06 ± 0.04	46.74 ± 0.47		44			13.38 ± 0.15	1.98
September	0.49 ± 0.03	19.1 ± 0.6	48.8 ± 2.4	39	131.9 ± 6.5	269	13.87 ± 0.15	5.74
October	0.26 ± 0.02	6.75 ± 0.26	6.34 ± 0.76	26	22.6 ± 2.7	87	14.13 ± 0.15	2.31
November	0.60 ± 0.03	29.1 ± 0.9	19.8 ± 0.9	48	96.6 ± 4.4	161	14.73 ± 0.15	3.38
December	1.09 ± 0.13	59.3 ± 1.3	20.9 ± 0.8	50	139 ± 5	127	15.82 ± 0.20	1.29
1959 January	sample started first week April '59							

MONTHLY FALLOUT COLLECTIONS

California, West Los Angeles

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1956 December through 1957 December							4.94 ± 0.10	
1958 January	0.44 ± 0.02	7.2 ± 0.9		14			5.37 ± 0.10	1.49
February	0.90 ± 0.05	11.5 ± 1.0		11			6.28 ± 0.11	6.26
March	1.30 ± 0.08	33.6 ± 3.1		24			7.58 ± 0.13	5.25
April	1.50 ± 0.00	13.4 ± 0.2		9			9.08 ± 0.13	2.04
May	0.05 ± 0.03	2.4 ± 0.5		48			9.13 ± 0.14	0.01
June	0.10 ± 0.01	0.40 ± 0.04		4			9.23 ± 0.14	trace
July	0.160 ± 0.003	0.37 ± 0.04		2			9.39 ± 0.14	trace
August	0.08 ± 0.01	2.70 ± 0.07		36			9.46 ± 0.14	0.02
September	0.08 ± 0.03	2.30 ± 0.31	5.74 ± 0.48	29	15.5 ± 1.3	194	9.54 ± 0.14	0.03
October	0.15 ± 0.02	5.90 ± 0.26	4.16 ± 0.46	39	14.9 ± 1.6	99	9.69 ± 0.14	0.32
November	0.11 ± 0.02	3.88 ± 0.16	2.18 ± 0.25	35	10.6 ± 1.2	96	9.80 ± 0.15	trace
December	0.07 ± 0.02	1.45 ± 0.12		21	6.2 ± 0.8	89	9.87 ± 0.15	0.01
1959 January	sample started first week April '59							

MONTHLY FALLOUT COLLECTIONS

MONTHLY FALLOUT COLLECTIONS

California, Richmond

	Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1958	3/20-4/3/58	4.47 ± 0.07	88.5 ± 7.9		20			3.74 ± 1.04	6.64
		3.00 ± 0.05	75.0 ± 5.9		25				
	4/3-4/30/58	0.38 ± 0.01	6.07 ± 0.04		16			4.11 ± 1.04	2.57
		0.36 ± 0.01	4.06 ± 0.07		11				
	May	0.33 ± 0.01	6.7 ± 0.2		20			4.48 ± 1.04	0.80
		0.42 ± 0.01	6.8 ± 0.2		16				
	June	0.21 ± 0.00	1.28 ± 0.03	0.276 ± 0.008	6	0.313 ± 0.009	1.5	4.65 ± 1.05	0.47
		0.12 ± 0.00	1.47 ± 0.02	0.248 ± 0.015	12	0.281 ± 0.017	2.3		
	July	0.046 ± 0.003	0.88 ± 0.02	1.58 ± 0.02	19	2.39 ± 0.03	52	4.70 ± 1.08	0
		0.062 ± 0.003	0.92 ± 0.01	1.58 ± 0.02	15	2.39 ± 0.03	39		
	August	0.020 ± 0.001	0.537 ± 0.008	1.66 ± 0.03	27	3.39 ± 0.06	170	4.91 ± 1.08	0
		0.021 ± 0.001	0.543 ± 0.009	1.41 ± 0.03	26	2.88 ± 0.06	137		

MONTHLY FALLOUT COLLECTIONS

Florida, Coral Gables

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1957 April through January 6, 1958							5.63 ± 0.07	
1958 1/6-2/6	0.29 ± 0.01	4.9 ± 0.5		17			5.93 ± 0.08	2.63•
2/6-3/6	0.22 ± 0.01	2.7 ± 0.3		12			6.14 ± 0.08	1.76•
3/6-4/6	0.60 ± 0.00	5.3 ± 0.9		9			6.74 ± 0.08	5.08•
4/6-5/6	0.49 ± 0.03	10.3 ± 0.6		21			7.23 ± 0.08	1.70•
5/6-6/6	1.70 ± 0.04	47.4 ± 0.7		28			8.93 ± 0.09	16.47•
6/6-7/6	1.39 ± 0.08	22.43 ± 0.45		16			10.32 ± 0.12	9.31•
7/6-8/6	0.77 ± 0.02	41.46 ± 0.34		54			11.09 ± 0.12	4.30•
8/6-9/6	6.20 ± 0.12	55.04 ± 0.62		9			17.29 ± 0.17	9.82•
9/6-10/6	0.60 ± 0.03	26.1 ± 0.7	38.5 ± 1.0	44	142 ± 4	237	17.89 ± 0.17	3.76•
10/6-11/6	0.74 ± 0.04	26.3 ± 0.6	15.2 ± 0.5	36	54.3 ± 1.8	73	18.63 ± 0.18	3.27•
11/6-12/6	0.63 ± 0.03	28.8 ± 0.9	9.90 ± 0.63	46	47.1 ± 3.0	75	19.26 ± 0.18	4.25•
12/6-1/6/59	2nd milk by middle of April '59							5.91•
1958 January	sample not started 1st week April '59							

• For collection periods as shown.

MONTHLY FALLOUT COLLECTIONS

* For collection periods as shown.

MONTHLY FALLOUT COLLECTIONS

Hawaii, Oahu, AEC Lab, Coconut Island

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1957 June through January 6, 1958							4.82 ± 0.14	
1958 1/6-2/3	0.32 ± 0.02	4.8 ± 1.0		15			5.14 ± 0.14	
February	0.95 ± 0.05	9.3 ± 1.0		10			6.09 ± 0.15	
March	1.68 ± 0.09	25.8 ± 3.3		15			7.77 ± 0.17	
April	1.98 ± 0.12	0.4 ± 0.2		0.2			9.75 ± 0.21	
May	0.944 ± 0.039	17.4 ± 0.5		18			10.69 ± 0.21	
June	1.13 ± 0.03	29.99 ± 0.79		27			11.82 ± 0.22	
July	0.16 ± 0.04	3.76 ± 0.10		24			11.98 ± 0.22	
August	0.90 ± 0.06	31.37 ± 0.57		35			12.88 ± 0.23	
September	0.69 ± 0.04	9.60 ± 0.41	36.8 ± 2.7	15	99.5 ± 0.7	144	13.57 ± 0.23	
October	0.01 ± 0.02	0.67 ± 0.91	1.97 ± 0.67	67	7.0 ± 2.4	700	13.58 ± 0.23	
November	0.48 ± 0.04	27.4 ± 0.9		57			14.06 ± 0.23	
December			11.2 ± 0.5		74.6 ± 3.3			

MONTHLY FALLOUT COLLECTIONS

Hawaii, Oahu, Gartley Hall, Univ. of Hawaii

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in* inches
1957 June through January 6, 1958							2.81 ± 0.10	
1958 January	0.71 ± 0.03	10.5 ± 1.4		15			3.52 ± 0.10	3.30
February	0.36 ± 0.02	4.1 ± 0.6		11			3.88 ± 0.11	2.62
March	1.33 ± 0.08	28.3 ± 3.3		21			5.21 ± 0.13	17.75
April	0.84 ± 0.02	12.8 ± 0.5		15			6.05 ± 0.13	1.39
May	1.15 ± 0.04	10.0 ± 0.4		9			7.20 ± 0.14	2.37
June	1.21 ± 0.05	2.43 ± 0.76		2			8.41 ± 0.15	1.76
July	0.07 ± 0.01	3.99 ± 0.11		57			8.48 ± 0.15	3.42
August	0.70 ± 0.03	37.43 ± 0.66		54			9.18 ± 0.15	7.69
September	0.73 ± 0.04	18.7 ± 0.6	26.4 ± 1.2	26	71.4 ± 3.2	98	9.91 ± 0.16	1.48
October	1.56 ± 0.05	3.17 ± 0.22	28.7 ± 1.1	2.0	102.5 ± 3.9	66	11.47 ± 0.16	4.57
November	0.48 ± 0.03	22.4 ± 0.8	9.44 ± 0.79	46	37.7 ± 3.2		11.96 ± 0.17	0.77
December	1.12 ± 0.12	56.6 ± 1.2		51			13.08 ± 0.20	3.30
1959 January			19.4 ± 0.4		162 ± 3			

* Data reported by station.

MONTHLY FALLOUT COLLECTIONS

* Data reported by station.

MONTHLY FALLOUT COLLECTIONS

Hawaii, Oahu, Weather Station, Coconut Island

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches*
1957 July through January 6, 1958							3.93 ± 0.02	
1958 January	0.22 ± 0.01	3.4 ± 0.6		15			4.15 ± 0.02	1.76
February	0.70 ± 0.05	6.2 ± 1.2		9			4.85 ± 0.05	2.83
March	1.65 ± 0.08	23.4 ± 1.9		14			6.50 ± 0.10	15.41
April	0.90 ± 0.02	15.9 ± 0.3		18			7.40 ± 0.10	1.28
May	1.02 ± 0.04	7.1 ± 0.4		7			8.42 ± 0.11	1.85
June	0.08 ± 0.02	0.14 ± 0.01		2			8.50 ± 0.11	1.58
July	1.16 ± 0.04	52.0 ± 0.5		45			9.66 ± 0.12	3.29
August	0.51 ± 0.05	23.35 ± 0.36		46			10.17 ± 0.13	5.55
September	0.53 ± 0.03	16.6 ± 0.6	10.4 ± 0.7	31	28.1 ± 1.9	53	10.70 ± 0.13	2.36
October	0.89 ± 0.04	21.3 ± 0.5	6.57 ± 0.59	24	23.5 ± 2.1	26	11.59 ± 0.14	8.65
November	0.46 ± 0.04	17.6 ± 0.7		38			12.05 ± 0.15	1.50
December	1.48 ± 0.11	62.7 ± 1.1		42			13.53 ± 0.18	4.32
1959 January								5.43
February								5.00

* Data reported by station.

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MONTHLY FALLOUT COLLECTIONS

Illinois, Lemont

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1956 December through December 19, 1957							5.94 ± 0.07	
1958 January, February	0.30 ± 0.00	3.0 ± 0.4		10			6.24 ± 0.07	1.45
March	lost						---	0.33
April	0.57 ± 0.05	13.5 ± 0.9		24			6.81 ± 0.09	1.64
May	0.79 ± 0.03	16.1 ± 0.5		20			7.60 ± 0.09	3.12
June	4.87 ± 0.03	61.2 ± 2.0		13			12.47 ± 0.10	6.43
July	0.09 ± 0.01	1.15 ± 0.04		13			12.56 ± 0.10	4.74
August	3.67 ± 0.10	23.2 ± 0.4		6			16.23 ± 0.14	2.51
September	0.33 ± 0.04	13.5 ± 0.9		41			16.56 ± 0.15	1.86
October	0.76 ± 0.03	28.1 ± 0.8	14.9 ± 0.7	37	53.2 ± 2.5	70	17.32 ± 0.15	2.12
November	1.04 ± 0.07	56.1 ± 2.3	8.38 ± 0.40	54	40.9 ± 2.0	40	18.36 ± 0.16	1.58
December	2nd milk middle of April '59							0.57
1959 January	Not started first week April '59							

MONTHLY FALLOUT COLLECTIONS

Kentucky, Louisville

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1958 9/18-10/1	0.24 ± 0.02	3.95 ± 0.08		16			0.25 ± 0.01	2.83
	0.26 ± 0.01	3.68 ± 0.07		14				
October	0.52 ± 0.017	10.56 ± 0.11		20			0.715 ± 0.09	1.65
	0.41 ± 0.015	10.82 ± 0.11		26				
November	0.61 ± 0.02	11.48 ± 0.18		19			1.375 ± 0.11	2.77
	0.71 ± 0.02	—		—				
December	0.58 ± 0.02	23.82 ± 0.19		41			1.965 ± 0.11	1.19
	0.60 ± 0.02	24.10 ± 0.19		40				
1959 January	2.10 ± 0.03	95.65 ± 0.29		46			4.155 ± 0.17	5.51
	2.28 ± 0.03	97.83 ± 0.29		43				
February	1.63 ± 0.03	47.86 ± 0.19		29			5.745 ± 0.18	2.76
	1.54 ± 0.03	52.79 ± 0.21		34				

MONTHLY FALLOUT COLLECTIONS

New Jersey, Westwood

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1957 August through December							4.78 ± 0.46	
1958 January	1.15 ± 0.02 1.91 ± 0.02						6.31 ± 0.71	6.42
February	0.46 ± 0.01 1.00 ± 0.02						7.04 ± 0.81	
March	0.99 ± 0.02 1.02 ± 0.02						8.06 ± 0.81	4.92
April	1.61 ± 0.04 1.85 ± 0.04	45.6 ± 0.3 32.1 ± 0.3		28 17			9.79 ± 0.82	6.38
May	2.66 ± 0.03 2.95 ± 0.03	30.1 ± 0.3 34.2 ± 0.3		11 12			12.60 ± 1.04	3.98
June	1.06 ± 0.03 1.03 ± 0.02	10.5 ± 0.3 15.3 ± 0.2		10 15			13.65 ± 1.04	1.90
July	1.10 ± 0.02 1.11 ± 0.02	42.4 ± 0.4 45.8 ± 0.4		38 41			14.76 ± 1.04	2.78
August	1.21 ± 0.03 1.01 ± 0.03	26.3 ± 1.1 24.2 ± 1.0		21 24			15.87 ± 1.06	4.31
September	0.67 ± 0.02 0.73 ± 0.02	19.42 ± 0.29 18.40 ± 0.20		29 25			16.48 ± 1.06	2.66
October	1.67 ± 0.03 1.61 ± 0.03	73.77 ± 0.48 83.38 ± 0.44		44 52			18.12 ± 1.06	4.72
November	1.38 ± 0.02 1.38 ± 0.02	53.50 ± 0.28 53.11 ± 0.28		39 38			19.50 ± 1.06	3.46
December	0.76 ± 0.03 0.82 ± 0.02	25.74 ± 0.19 24.65 ± 0.16		34 30			20.29 ± 1.06	1.08

MONTHLY FALLOUT COLLECTIONS

December	0.76 ± 0.03 0.82 ± 0.02	25.74 ± 0.19 24.65 ± 0.16		34 30			20.29 ± 1.06	1.06	

New York, New York

Sampling Period		millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'm. in inches
2-1-54 to 12-31-57								39.27 ± 0.75	
1958	January	1.20 ± 0.05 1.37 ± 0.05			21 17			40.52 ± 0.75	3.79
	February	1.23 ± 0.07			13			41.75 ± 0.75	2.98
	March	0.94 ± 0.07 0.84 ± 0.07			16 18			42.64 ± 0.75	3.19
	April	1.52 ± 0.42(1)			10.5 ± 6(3)			44.17 ± 0.86	6.14
	May	2.70 ± 0.07 2.57 ± 0.06	5.29 ± 0.52 4.60 ± 0.46		11 10			46.80 ± 0.86	3.25
	June	1.84 ± 0.06 1.67 ± 0.05	5.04 ± 0.46 4.95 ± 0.46		11 12			48.55 ± 0.86	2.55
	July	1.58 ± 0.29(2)	16.9 ± 2.0(2)		11			50.13 ± 0.91	3.68
	August	0.60 ± 0.05(1)	11.5 ± 2.2(1)		20			50.73 ± 0.91	2.36
	September	0.65 ± 0.11(1)	14.94 ± 0.65 17.64 ± 0.27		28 ± 1(3)			51.38 ± 0.92	4.44
	October	1.06 ± 0.33(1)	38.01 ± 0.67 48.25 ± 0.58		53 ± 15(3)			52.44 ± 0.97	5.46
	November	0.98 ± 0.21(1)	18.05 ± 0.48 26.53 ± 0.42		29 ± 11(3)			53.31 ± 1.00	1.85
	December	1.77 ± 0.48(1)	71.7 ± 0.8 70.5 ± 0.9		46 46				1.85
1959	1/13-1/30	1.19 ± 0.13(1)	27.9 ± 0.4 31.9 ± 0.5		23 30				

(1) Four analyses.
(2) Three analyses.
(3) Two Sr^{89} analyses.

MONTHLY FALLOUT COLLECTIONS

Oklahoma, Tulsa

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958 January	0.35 ± 0.02	5.3 ± 0.7		15			0.35 ± 0.02	1.78
February	0.40 ± 0.02	3.0 ± 0.3		8			0.75 ± 0.03	0.86
March	2.29 ± 0.06	22.7 ± 1.0		10			3.04 ± 0.07	6.14
April	2.84 ± 0.15	34.2 ± 1.1		12			5.88 ± 0.16	4.64
May	2.22 ± 0.67	20.1 ± 0.7		9			8.10 ± 0.69	3.44
June	1.47 ± 0.05	22.1 ± 0.72		15			9.57 ± 0.69	3.08
July	1.92 ± 0.05	169.2 ± 1.03		88			11.49 ± 0.69	3.33
August	1.05 ± 0.03	55.46 ± 0.45		53			12.54 ± 0.69	3.58
September	0.90 ± 0.03	32.7 ± 0.9	44.3 ± 1.6	36	120 ± 4	133	13.44 ± 0.69	3.61
October	0.20 ± 0.02	4.59 ± 0.35	17.1 ± 0.6	23	61.1 ± 2.1	306	13.64 ± 0.69	0.21
November	0.47 ± 0.02	3.86 ± 0.23		8			14.11 ± 0.69	1.39
December	0.57 ± 0.03	26.0 ± 1.0		46			14.68 ± 0.69	0.82

MONTHLY FALLOUT COLLECTIONS

MONTHLY FALLOUT COLLECTIONS

Pennsylvania, Pittsburgh

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at sampling midpoint	mc W^{185}/mi² on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi²	ppt'n. in inches
1957 July 3 through December 31							2.07 ± 0.21	
1958 January	0.57 ± 0.03	4.4 ± 0.7	---	7	---	--	2.64 ± 0.21	3.40
	0.57 ± 0.03	4.3 ± 0.5	---	7	---	--		
February	0.29 ± 0.02	3.5 ± 0.5	---	12	---	--	2.95 ± 0.21	1.00
	0.33 ± 0.03	4.2 ± 0.5	---	12	---	--		
March	0.41 ± 0.02	5.3 ± 0.6	---	12	---	--	3.36 ± 0.21	3.36
	0.42 ± 0.02	5.1 ± 0.5	---	12	---	--		
April	1.20 ± 0.09	19.6 ± 2.0	---	15	---	--	4.23 ± 0.50	3.87
	0.54 ± 0.54	7.7 ± 1.3	---	13	---	--		
May	0.76 ± 0.04	8.4 ± 0.8	< 2.30	11	< 2.30	< 3	4.98 ± 0.51	3.87
	0.73 ± 0.04	9.7 ± 0.8	1.35 ± 0.43	13	1.35 ± 0.43	2		
June	2.28 ± 0.14	34. ± 3.	6.73 ± 0.82	15	7.65 ± 0.93	3	7.19 ± 0.52	3.00
	2.15 ± 0.12	36 ± 3	7.96 ± 0.82	17	9.05 ± 0.93	4		
July	1.89 ± 0.09	96 ± 8	73.0 ± 2.7	51	111 ± 4	59	9.22 ± 0.56	8.47
	2.16 ± 0.12	90 ± 6	73.0 ± 2.7	42	111 ± 4	51		
August	1.44 ± 0.08	43 ± 4	36.1 ± 1.3	30	73.7 ± 2.7	51	10.67 ± 0.57	5.33
	1.47 ± 0.12	40 ± 3	36.8 ± 1.3	27	75.1 ± 2.7	51		
September	0.59 ± 0.03	18.3 ± 0.8	19.2 ± 1.0	31	51.9 ± 2.7	88	11.26 ± 0.57	4.34
	0.59 ± 0.03	15.9 ± 0.7	16.0 ± 0.7	27	43.2 ± 1.9	73		
October	0.48 ± 0.02	16.7 ± 0.7	17.5 ± 0.8	35	62.5 ± 2.9	130	11.74 ± 0.57	3.13
	0.49 ± 0.02	14.2 ± 0.8	lost	29	---	--		
November	0.66 ± 0.04	24.8 ± 2.0	8.1 ± 0.4	38	39.5 ± 2.0	60	12.38 ± 0.57	
	0.62 ± 0.03	24.7 ± 1.2	11.1 ± 0.6	40	54.1 ± 2.9	87		
December	0.65 ± 0.03	19.5 ± 1.8	4.7 ± 0.3	30	27.6 ± 1.5	42	13.04 ± 0.57	
	0.67 ± 0.03	19.0 ± 0.8	5.6 ± 0.3	28	32.9 ± 1.5	49		
1959 January	1.38 ± 0.06	34.5 ± 1.2	5.7 ± 0.3	25	47.5 ± 2.5	34	14.29 ± 0.57	4.01
	1.12 ± 0.05	34.0 ± 1.8	11.8 ± 0.4	30	98.3 ± 3.3	88		

MONTHLY FALLOUT COLLECTIONS

South Dakota, Vermillion

	Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at sampling midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1957	April through December							9.18 ± 0.19	
1958	January	0.08 ± 0.01	1.39 ± 0.4		17			9.26 ± 0.19	0.22
	February	0.38 ± 0.02	5.5 ± 0.5		13			9.64 ± 0.19	2.13
	March	0.20 ± 0.01	2.79 ± 0.3		13			9.84 ± 0.19	0.52
	April	2.54 ± 1.00	31.0 ± 1.0		11			12.38 ± 0.19	3.15
	May	2.28 ± 0.06	36.0 ± 1.0		16			14.66 ± 0.21	1.85
	June	0.16 ± 0.02	0.87 ± 0.04		5			14.82 ± 0.21	1.09
	July	2.42 ± 0.08	75.94 ± 1.39		31			17.24 ± 0.22	4.47
	August	0.50 ± 0.02	24.60 ± 0.50		49			17.74 ± 0.22	0.19
	September	0.29 ± 0.02	12.5 ± 0.4	5.49 ± 0.87	43	14.8 ± 2.4	51	18.03 ± 0.23	0.88
	October	0.06 ± 0.01	1.37 ± 0.15	2.90 ± 0.40	23	10.4 ± 1.4	173	18.09 ± 0.23	0
	November	0.74 ± 0.04	34.8 ± 1.0	11.6 ± 0.5	47	56.6 ± 2.4	76	18.83 ± 0.23	0.94
	December	0.21 ± 0.03	7.82 ± 0.32	3.92 ± 0.82	37	26.1 ± 5.5	124	19.04 ± 0.23	0.07
1959	January	sample started first week April '59							

MONTHLY FALLOUT COLLECTIONS

Texas, Houston

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at sampling midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958 May	0.37 ± 0.01	3.6 ± 0.1	---	10	---	--	0.38 ± 0.01	1.55
	0.38 ± 0.02	3.4 ± 0.2	---	9	---	--		
June	0.67 ± 0.03	15.6 ± 0.3	lost	23	---	--	1.08 ± 0.32	2.10
	0.74 ± 0.02	18.7 ± 0.3	20 ± 1	23	22.7 ± 1.1	31		
July	0.62 ± 0.02	41.0 ± 0.7	56 ± 1	66	84.8 ± 1.5	137	1.63 ± 0.52	1.94
	0.48 ± 0.02	31.5 ± 0.5	55 ± 1	66	83.3 ± 1.5	174		
8-1 to 9-8	0.61 ± 0.02	32 ± 1	80 ± 1	53	168 ± 2	275	2.24 ± 0.52	6.44
	0.61 ± 0.02	37 ± 1	82 ± 2	61	173 ± 4	284		

MONTHLY FALLOUT COLLECTIONS

Utah, Salt Lake City

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at sampling midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1956 December through 1957 December							13.06 ± 0.19	
1958 January	0.70 ± 0.05	10.7 ± 1.0		15			13.76 ± 0.19	0.87
February	1.10 ± 0.04	13.9 ± 1.7		13			14.86 ± 0.20	2.20
March	1.47 ± 0.08	46.5 ± 0.4		32			16.33 ± 0.22	2.19
April	2.10 ± 0.05	26.9 ± 0.3		13			18.43 ± 0.22	2.92
May	1.30 ± 0.06	15.8 ± 0.8		12			19.73 ± 0.23	0.30
June	0.28 ± 0.02	3.26 ± 0.20		12			20.01 ± 0.23	0.04
July	0.060± 0.003	6.44 ± 0.35		107			20.07 ± 0.23	0.05
August	0.71 ± 0.11	31.55 ± 0.64		44			20.78 ± 0.26	0.25
September								0.25
October	0.10 ± 0.03	4.68 ± 0.32	3.34 ± 0.48	47	11.9 ± 1.7	119		trace
November	0.25 ± 0.02	4.04 ± 0.18		16				1.13
12/12-1/12/59	3.07 ± 0.15	131 ± 2	16.0 ± 0.4	43	107 ± 3	35		0.54
1959 January	sample started first week April '59							

MONTHLY FALLOUT COLLECTIONS

Australia, Darwin

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1958 July	0.43 ± 0.01	5.71 ± 0.11		13			0.43 ± 0.01	0.12
August	0.04 ± 0.01	0.91 ± 0.18	3.43 ± 0.82	23	6.86 ± 1.64	172	0.47 ± 0.01	0.01*
September	1.24 ± 0.04	53.2 ± 1.3	1.40 ± 0.48	43	3.8 ± 1.3	3		0
October	0.26 ± 0.02	6.34 ± 0.32	6.63 ± 0.53	24	23.7 ± 1.9	91		
November	0.27 ± 0.02	20.6 ± 0.7	6.40 ± 0.38	76	25.6 ± 1.5	95		5.07
December			5.40 ± 0.31		36.0 ± 2.1			7.16*

* Data reported by station.

MONTHLY FALLOUT COLLECTIONS

Australia, Melbourne

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1958 June	0.08 ± 0.01	0.20 ± 0.05		3			0.08 ± 0.01	
July	0.05 ± 0.01	1.07 ± 0.06		21			0.13 ± 0.01	
August	0.18 ± 0.01	2.22 ± 0.40	3.10 ± 0.86	12	6.3 ± 1.8	17	0.31 ± 0.02	3.19*
September	0.24 ± 0.02	6.64 ± 0.32	4.26 ± 0.31	28	11.5 ± 0.8	48	0.55 ± 0.03	3.12
October	0.45 ± 0.03	8.92 ± 0.33	7.66 ± 0.39	20	27.4 ± 1.4	61	1.00 ± 0.04	3.90
November	2nd milk by middle of April '59							1.25*
December	sample started first week April '59							
1959 January	sample not started 1st week April '59							

* Data reported by station.

MONTHLY FALLOUT COLLECTIONS

Australia, Perth

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1958 6/11-7/1	0.093 ± 0.003	0.83 ± 0.4		9			0.093 ± 0.003	
July	0.156 ± 0.001	2.40 ± 0.06		15			0.249 ± 0.003	16.38
August	0.18 ± 0.01	7.18 ± 1.44	5.08 ± 0.78	40	10.4 ± 1.6	58	0.43 ± 0.01	2.66*
September	0.33 ± 0.02	10.2 ± 0.4	5.24 ± 0.62	31	14.2 ± 1.7	43	0.76 ± 0.02	0.20
October	0.11 ± 0.02	2.23 ± 0.27	1.54 ± 0.36	20	5.5 ± 1.3	50	0.87 ± 0.03	2.73
November	0.11 ± 0.02	1.90 ± 0.17	2.88 ± 0.34	17	14.0 ± 1.7	127	0.98 ± 0.06	0.39
December			2.44 ± 0.28		16.2 ± 1.9			0.49*
1959 January	sample not started 1st week April '59							

* Data reported by station.

MONTHLY FALLOUT COLLECTIONS

Australia, Sydney

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1958 6/3-7/1	0.34 ± 0.02	0.32 ± 0.08		1			0.34 ± 0.02	
July	0.26 ± 0.01	6.06 ± 0.13		23			0.60 ± 0.02	1.17
August	0.44 ± 0.02	19 ± 1	10.3 ± 1.0	43	21.0 ± 2.0	48	1.04 ± 0.03	3.71•
September	0.25 ± 0.02	(-) 0.47 ± 0.13	1.51 ± 0.71	--	4.1 ± 1.9	16	1.29 ± 0.04	1.17
October	0.24 ± 0.02	6.13 ± 0.28	4.59 ± 0.34	26	16.4 ± 1.2	68	1.53 ± 0.04	2.34
November	0.21 ± 0.02	3.17 ± 0.19	3.91 ± 0.37	15	19.1 ± 1.8	91	1.74 ± 0.04	0.78
December			3.63 ± 0.43		24.2 ± 2.9			5.84•

• Data reported by station.

MONTHLY FALLOUT COLLECTIONS

Australia, Townsville

Sampling Period		millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1958	6/6-7/1	0.25 ± 0.01	3.93 ± 0.04		16			0.25 ± 0.01	
	July	0.10 ± 0.01	0.43 ± 0.02		4			0.35 ± 0.01	0
	August	0.07 ± 0.02	0.90 ± 0.13	3.59 ± 0.82	13	7.18 ± 1.64	103	0.42 ± 0.02	0.07*
	September	lost							0.23
	October	0.06 ± 0.03	1.14 ± 0.34	6.75 ± 0.48	19	24.1 ± 1.7			0.12
	November	2nd milk by middle of April '59							1.17
	December			2.40 ± 0.35		16.0 ± 2.3			3.49*
1959	January	sample not started first week April '59							

* Data reported by station.

MONTHLY FALLOUT COLLECTIONS

Australia, Brisbane

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at sampling midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n in inches
1958 June	0.053 ± 0.008	2.25 ± 0.07		42			0.053 ± 0.03	
July	0.011 ± 0.001	0.00 ± 0.004		—			0.064 ± 0.03	0
August	0.16 ± 0.01	7.39 ± 0.54	4.49 ± 0.98	46	9.2 ± 2.0	58	0.227 ± 0.033	1.65*
September	0.29 ± 0.02	8.72 ± 0.36	5.98 ± 0.60	30	16.2 ± 1.6	56	0.517 ± 0.039	1.95
October	0.95 ± 0.04	58.4 ± 1.3	23.7 ± 0.7	61	84.6 ± 2.5	90	1.47 ± 0.056	1.56
November	2nd milk middle of April '59							1.56
December	sample started first week April '59							1.17

* Data reported by station.

MONTHLY FALLOUT COLLECTIONS

Australia, Adelaide

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at sampling midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958 6/6-7/1	0.036 ± 0.011	0.66 ± 0.04		18			0.04 ± 0.01	3.12
July	0.16 ± 0.01	2.22 ± 0.06		14			0.20 ± 0.02	1.17
August	0.33 ± 0.02	4.8 ± 0.9	8.65 ± 0.98	15	17.7 ± 2.0	54	0.53 ± 0.02	2.35*
September	0.50 ± 0.03	8.95 ± 0.39	7.23 ± 0.44	18	19.5 ± 1.2	38	1.03 ± 0.04	3.00*
October	0.71 ± 0.04	13.0 ± 0.4	11.2 ± 0.5	18	40.0 ± 1.8	56	1.74 ± 0.05	2.34
November	0.21 ± 0.03	2.88 ± 0.25		14			1.95 ± 0.06	
December			2.41 ± 0.78		16.0 ± 5.2			0.25

* Data reported by station.

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MONTHLY FALLOUT COLLECTIONS

Washington, Seattle

	Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at sampling midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958	4/18-30	0.51 ± 0.01	7.46 ± 0.15		15			0.51 ± 0.01	1.34
	May	2.12 ± 0.06	12.3 ± 0.36		6			2.63 ± 0.06	0.92
	June	0.57 ± 0.05	14.75 ± 0.40		26			3.20 ± 0.08	0.72
	July	0.040 ± 0.003	0.16 ± 0.04		4			3.24 ± 0.08	trace
	8/1-9/3	0.158 ± 0.014	1.22 ± 0.05		8			3.40 ± 0.08	0.32
	September	0.50 ± 0.03	24.6 ± 0.7	87.4 ± 6.6	49	236 ± 18	472	3.90 ± 0.08	1.47
	October	0.64 ± 0.03	30.8 ± 0.7	7.77 ± 0.56	48	27.8 ± 2.0	43	4.04 ± 0.09	3.12
	November	sample lost at site							6.53
	December	1.62 ± 0.09	202 ± 3	9.50 ± 0.35	125	55.9 ± 2.1	35		5.51
1959	January			16.4 ± 0.5		126 ± 4			

MONTHLY FALLOUT COLLECTIONS

Austria, Klagenfurt

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1957 August through December							1.90 ± 0.06	
1958 January	0.13 ± 0.01	3.1 ± 0.4		24			2.03 ± 0.06	2.73
February	0.17 ± 0.02	1.6 ± 0.2		10			2.20 ± 0.07	2.34
March	1.15 ± 0.05	33 ± 0.7		29			3.35 ± 0.08	1.56
April	1.26 ± 0.06	23 ± 1.0		18			4.61 ± 0.11	
May	0.49 ± 0.03	8.7 ± 0.3		18			5.10 ± 0.11	1.56
June								8.19
July	3.51 ± 0.12	19.34 ± 0.72		6				5.07
August	2.28 ± 0.06	62.0 ± 1.8	34.9 ± 1.5	27	71.2 ± 3.1	31		6.63
September	0.80 ± 0.04	20.7 ± 0.8	26.4 ± 1.0	26	71.4 ± 2.7	89		2.73
October	0.66 ± 0.03	14.4 ± 0.5	11.6 ± 1.0	22	41.4 ± 0.1	63		3.12
November	0.46 ± 0.02	23.7 ± 0.7	7.99 ± 0.43	52	39.0 ± 2.1	85		3.90
December			5.22 ± 0.40		34.8 ± 2.7			3.51

MONTHLY FALLOUT COLLECTIONS

Austria, Vienna

Sampling Period	millicuries per square mile at midpoint of sampling period: Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1957 June through December							4.14 ± 0.11	
1958 January	0.16 ± 0.01	4.0 ± 0.5		25			4.30 ± 0.11	1.17
February	0.27 ± 0.02	3.9 ± 0.7		14			4.57 ± 0.11	2.34
March	0.35 ± 0.01	5.4 ± 0.2		15			4.92 ± 0.11	2.73
April	0.71 ± 0.05	12.7 ± 0.9		18			5.63 ± 0.12	
May	0.692 ± 0.034	11.5 ± 0.4		17			6.32 ± 0.12	0.78
June	3.13 ± 0.08	2.8 ± 0.4		1			9.45 ± 0.15	5.85
July	1.07 ± 0.03	13.29 ± 0.45		12			10.52 ± 0.15	1.95
August	1.84 ± 0.09	37.2 ± 1.6	36.3 ± 1.8	20	74.1 ± 3.7	40	12.36 ± 0.18	3.90
September	0.02 ± 0.02	8.26 ± 0.38	1.52 ± 0.83	413 ?	4.1 ± 2.2	76	12.38 ± 0.18	0.78
October	0.76 ± 0.04	24.6 ± 0.8	13.0 ± 0.8	34	46.4 ± 2.9	61	13.14 ± 0.18	2.73
November	0.48 ± 0.04	20.1 ± 0.7	7.01 ± 0.28	42	28.0 ± 1.1	58	13.62 ± 0.18	1.17
December			6.92 ± 0.53		46.1 ± 3.5			2.73

MONTHLY FALLOUT COLLECTIONS

Brasil, Itaici, State of São Paulo

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958 August	0.262 ± 0.019	16.3 ± 1.0	14.1 ± 1.2	62			0.262 ± 0.019	
September	Sample at HSBC							
October	0.50 ± 0.03	16.4 ± 0.6	6.35 ± 1.67	33	22.7 ± 6.0	45	0.76 ± 0.04	
November	0.36 ± 0.03	25.4 ± 1.0	3.52 ± 0.33	71	14.0 ± 1.3	39	1.12 ± 0.05	

MONTHLY FALLOUT COLLECTIONS

Brazil, Nova Friburgo, State of Rio

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958 8/3-8/29	0.14 ± 0.02	2.91 ± 0.43		21			0.14 ± 0.02	
September	0.48 ± 0.03	31.1 ± 0.9	21.8 ± 1.0	65	58.9 ± 2.7	123	0.62 ± 0.04	
October	0.83 ± 0.03	13.1 ± 0.4	26.7 ± 0.7	16	95.4 ± 2.8	115	1.45 ± 0.05	
November								

MONTHLY FALLOUT COLLECTIONS

Brazil, São José dos Campos, State of São Paulo

	Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1958	July	0.12 ± 0.02	2.93 ± 0.43	6.1 ± 1.0	24	9.4 ± 1.5	78		
	August								
	September			14.5 ± 1.2		39.1 ± 3.2			
	October	0.62 ± 0.03	36.8 ± 0.9	7.34 ± 0.80	59	26.2 ± 2.9	42		
	November	0.48 ± 0.03	9.39 ± 0.50		20				

MONTHLY FALLOUT COLLECTIONS

Chile, Santiago

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958 June								4.29
July	0.13 ± 0.01	6.90 ± 0.13		53				
August	0.58 ± 0.03	35.8 ± 1.4	17.9 ± 1.1	62	36.5 ± 2.2	63		
September	0.09 ± 0.02	3.06 ± 0.28	1.40 ± 0.11	34	3.8 ± 0.3	42		0.39
October	0.27 ± 0.03	8.88 ± 0.47	7.94 ± 0.49	33	28.4 ± 1.8	105		0
November	0.18 ± 0.02	3.54 ± 0.25		20				0.39
December			0.14 ± 0.41		0.93 ± 2.73			0

MONTHLY FALLOUT COLLECTIONS

Columbia, Bogota

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1958 January	0.04 ± 0.01	0.49 ± 0.1		12			0.10 ± 0.02	0.35
February	0.04 ± 0.01	0.58 ± 0.2		15			0.14 ± 0.02	0.61
March	0.12 ± 0.01	0.46 ± 0.04		4			0.26 ± 0.02	1.79
April	0.025 ± 0.02	0.82 ± 0.29		33			0.29 ± 0.03	2.89
May	0.12 ± 0.01	1.55 ± 0.10		13			0.41 ± 0.03	1.05
June	0.02 ± 0.03	2.66 ± 0.04		133 †			0.43 ± 0.03	
July	0.10 ± 0.01	4.40 ± 0.11		43			0.53 ± 0.10	
August	0.20 ± 0.02	18.4 ± 0.6	9.37 ± 0.69	92	19.1 ± 1.4	96	0.73 ± 0.12	
September	0.06 ± 0.02	4.31 ± 0.32	3.01 ± 0.49	72	8.1 ± 1.3	14	0.79 ± 0.13	
October	0.09 ± 0.02	3.75 ± 0.34	5.72 ± 0.41	416 †	20.4 ± 1.5	227 †	0.88 ± 0.13	
November	0.10 ± 0.02	4.38 ± 0.27	8.27 ± 0.05	44			0.98 ± 0.13	
December	sample not started first week April '59							

MONTHLY FALLOUT COLLECTIONS

Japan, Hiroshima

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1956 August through December 1957							5.80 ± 0.12	
1958 January	0.24 ± 0.04	5.4 ± 0.7		23			6.04 ± 0.13	2.65
February	0.25 ± 0.01	2.9 ± 0.3		12			6.29 ± 0.13	2.95
March	0.92 ± 0.06	10.5 ± 1.0		11			7.21 ± 0.14	4.88
April	3.37 ± 0.02	36.0 ± 0.9		10			10.58 ± 0.14	10.49
May	1.06 ± 0.06	14.1 ± 0.8		14			11.64 ± 0.15	3.74
June	0.64 ± 0.02	6.69 ± 0.24		11			12.28 ± 0.15	3.98
July	0.43 ± 0.02	0.000 ± 0.003		--			12.71 ± 0.15	6.90
August	2.66 ± 0.07	44.9 ± 0.6		17			15.37 ± 0.17	9.87
September	0.42 ± 0.03	22.0 ± 0.7	26.5 ± 1.1	52	71.6 ± 3.0	63	15.79 ± 0.17	3.59
October	0.79 ± 0.03	37.8 ± 0.9	1.03 ± 0.27	48	3.7 ± 1.0	5	16.58 ± 0.17	4.88
November	0.71 ± 0.04	5.85 ± 0.37		8			17.29 ± 0.18	2.38
December	0.57 ± 0.08	35.6 ± 0.8		62			17.86 ± 0.19	1.95
1959 January	sample started first week April '59							

MONTHLY FALLOUT COLLECTIONS

Japan, Nagasaki

Sampling Period	millicuries per square mile at midpoint of sampling period: Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1956 August through December 1957							7.90 ± 0.15	
1958 January	0.60 ± 0.05	9.9 ± 1.5		16			8.50 ± 0.16	2.50
February	0.55 ± 0.03	6.0 ± 0.8		11			9.05 ± 0.16	2.77
March	1.13 ± 0.06	15.8 ± 1.2		14			10.18 ± 0.17	5.38
April	2.52 ± 0.07	38.7 ± 1.2		15			12.70 ± 0.19	14.94
May	1.75 ± 0.06	7.2 ± 0.7		4			14.45 ± 0.20	7.29
June	0.88 ± 0.11	30.6 ± 1.1		35			15.33 ± 0.23	5.93
July	2.10 ± 0.05	180.7 ± 0.9		86			17.43 ± 0.23	1.33
August	0.50 ± 0.03	29.9 ± 0.6		60			17.93 ± 0.23	14.27
September	0.26 ± 0.03	13.5 ± 0.5	17.3 ± 1.1	52	46.8 ± 5.0	180	18.19 ± 0.24	2.77
October	0.55 ± 0.03	24.0 ± 0.7	12.6 ± 0.6	44	45.0 ± 2.1	82	18.74 ± 0.24	6.67
November	0.61 ± 0.03	29.3 ± 0.9	7.32 ± 0.46	48	35.7 ± 2.2		19.35 ± 0.24	2.11
December			25.1 ± 0.8		167.3 ± 5.3			3.86
1959 January			13.6 ± 0.6		113.3 ± 5.0			

MONTHLY FALLOUT COLLECTIONS

Kenya, Kikuyu

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1957 January through December							1.30 ± 0.07	
1958 January	0.03 ± 0.01	0.71 ± 0.35		24			1.33 ± 0.07	0.90•
February	0.14 ± 0.03	1.64 ± 0.21		12			1.47 ± 0.08	5.46•
March	0.22 ± 0.01	1.08 ± 0.04		5			1.69 ± 0.08	3.41•
April	0.13 ± 0.01	0.75 ± 0.16		6			1.82 ± 0.08	4.79•
May	0.90 ± 0.05	4.92 ± 0.06		5			2.72 ± 0.10	11.82•
June	0.22 ± 0.01	6.6 ± 0.2		30			2.94 ± 0.10	
July	0.26 ± 0.01	12.6 ± 0.2		48			3.20 ± 0.10	
August	0.13 ± 0.01	3.1 ± 0.1		24			3.33 ± 0.10	
September	0.07 ± 0.05	3.50 ± 0.91	3.58 ± 0.43	50	9.7 ± 1.2	139	3.40 ± 0.11	
October	0.25 ± 0.02	6.46 ± 0.23	2.77 ± 0.33	26	9.8 ± 1.2	39	3.65 ± 0.11	
November	0.15 ± 0.03	5.48 ± 0.27	3.58 ± 0.65	37	14.3 ± 2.6		3.80 ± 0.11	
December	2nd milk middle of April '59							2.54•
1959 January	sample not started first week April '59							

• Data reported by station.

* Data reported by station.

MONTHLY FALLOUT COLLECTIONS

Pakistan, Karachi

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958 February	0.02 ± 0.01	0.91 ± 0.18		45			0.02 ± 0.01	0.39
March	0.07 ± 0.00	0.28 ± 0.02		40			0.09 ± 0.01	0
April	0.13 ± 0.01	0.50 ± 0.03		4			0.22 ± 0.01	0
May	0.39 ± 0.01	0.96 ± 0.03		3			0.61 ± 0.02	0
June	0.07 ± 0.01	0.92 ± 0.05		13			0.68 ± 0.02	0
July	0.29 ± 0.02	15.4 ± 1.0	5.42 ± 0.96	53	8.2 ± 1.5	7	0.97 ± 0.03	
August	0.15 ± 0.04	4.70 ± 0.57	lost	31			1.12 ± 0.05	
September	0.56 ± 0.03	34.2 ± 0.8		61			1.68 ± 0.06	
October	0.06 ± 0.01	0.93 ± 0.24		16			1.74 ± 0.06	
November	0.04 ± 0.02	0.35 ± 0.16		9			1.78 ± 0.06	0
December			11.1 ± 0.7		74.0 ± 4.7			0.04

MONTHLY FALLOUT COLLECTIONS

Senegal, Dakar

	Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt's. in inches
1958	7/5-8/4	0.23 ± 0.02	0.000 ± 0.003					0.23 ± 0.02	0
	8/4-9/4	0.033 ± 0.005	0.000 ± 0.004					0.26 ± 0.02	0
	9/5-10/5			21.9 ± 0.9		59.2 ± 2.4			
	10/5-11/5								
	11/5-12/5								
	12/5-1/5/59								

MONTHLY FALLOUT COLLECTIONS

Southern Rhodesia, Salisbury

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1957 November through December							0.21 ± 0.02	
1958 January	0.10 ± 0.01	0.39 ± 0.13		4			0.31 ± 0.02	5.87
February	0.04 ± 0.01	0.23 ± 0.05		5			0.35 ± 0.02	8.98
March	0.02 ± 0.01	0.13 ± 0.03		7			0.37 ± 0.03	0.57
April	0.16 ± 0.01	2.82 ± 0.02		18			0.53 ± 0.03	1.87
May	0.55 ± 0.04						1.08 ± 0.05	trace
June	0.02 ± 0.003	0.19 ± 0.02		9			1.10 ± 0.05	
July	0.02 ± 0.003	0.27 ± 0.03		14			1.12 ± 0.05	
August	0.05 ± 0.004	0.000 ± 0.004					1.17 ± 0.05	
September	0.17 ± 0.02	12.1 ± 0.4	9.23 ± 0.56	71	24.9 ± 1.5	146	1.34 ± 0.05	
October	0.43 ± 0.03	13.6 ± 0.8	9.81 ± 0.61	32	35.0 ± 2.2	81	1.77 ± 0.06	
November	0.35 ± 0.04	4.28 ± 0.21	10.1 ± 0.4	12	40.4 ± 1.6	115	2.12 ± 0.07	
December	0.41 ± 0.03	3.82 ± 0.24	8.18 ± 0.35	9	54.5 ± 2.3	133	2.53 ± 0.08	4.67
1959 January	sample not started first week April '59							

MONTHLY FALLOUT COLLECTIONS

Taiwan, Tainan

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in* inches
1958 January	0.03 ± 0.01	0.75 ± 0.14		25			0.03 ± 0.01	0.86
February	0.07 ± 0.01	0.87 ± 0.12		12			0.10 ± 0.01	0.77
March	0.19 ± 0.02	1.91 ± 0.19		10			0.29 ± 0.02	3.49
April	0.05 ± 0.00	0.62 ± 0.01		12			0.34 ± 0.02	0.15
May	0.412 ± 0.024	23.8 ± 0.56		58			0.75 ± 0.03	4.92
June	0.22 ± 0.02	10.3 ± 0.6		47			0.97 ± 0.04	3.74
July	1.01 ± 0.02	66.0 ± 0.4		65			1.98 ± 0.04	28.21
August	0.30 ± 0.01	3.0 ± 0.1		10			2.28 ± 0.05	
September	0.37 ± 0.02	18.4 ± 0.5	6.88 ± 0.40	50	18.6 ± 1.1	50	2.65 ± 0.05	
October	0.01 ± 0.02	1.58 ± 2.84	2.49 ± 0.40	158 ?	8.9 ± 1.4	890 ?	2.66 ± 0.05	
November	0.01 ± 0.02	1.10 ± 2.48	0.06 ± 0.05	110 ?	0.24 ± 0.20	24 ?	2.67 ± 0.05	
December			10.0 ± 1.0		66.6 ± 6.7			
1959 January			1.24 ± 0.20		10.3 ± 1.7			

* Data reported by station.

* Data reported by station.

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Taiwan, Taipei

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1958 February	0.15 ± 0.01	1.4 ± 0.2		9			0.15 ± 0.01	9.57*
March	0.10 ± 0.01	1.4 ± 0.02		14			0.25 ± 0.01	5.40*
April	0.57 ± 0.01	6.3 ± 0.3		11			0.82 ± 0.02	2.24*
May	0.31 ± 0.03	11.4 ± 0.3		37			1.13 ± 0.03	4.13*
June	1.01 ± 0.03	34.6 ± 0.7		34			2.14 ± 0.04	8.49*
July	0.07 ± 0.01	22.9 ± 0.3		327 ?			2.21 ± 0.05	20.43*
August	0.57 ± 0.02	29.3 ± 0.3		51			2.78 ± 0.05	4.68
September	0.23 ± 0.02	10.8 ± 0.4	18.7 ± 0.7	47	50.5 ± 1.9	220	3.01 ± 0.05	7.02
October	0.80 ± 0.03	43.4 ± 1.2	16.6 ± 0.6	54	59.3 ± 2.1	74	3.81 ± 0.06	3.51
November	1.13 ± 0.12	49.7 ± 1.3	17.2 ± 0.5	44	83.9 ± 2.4	74	4.94 ± 0.13	1.95
December	2.01 ± 0.15	63.9 ± 1.4	18.2 ± 0.5	32	107.1 ± 2.9	53	6.95 ± 0.20	5.85
1959 January			15.9 ± 0.5		115.8 ± 4.1			

* Data reported by station.

MONTHLY FALLOUT COLLECTIONS

Taiwan, Taitung

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958 April	0.22 ± 0.01	2.29 ± 0.13		10			0.22 ± 0.01	1.17
May	0.184 ± 0.023	4.6 ± 0.2		25			0.40 ± 0.02	6.86
June	0.57 ± 0.06	32.1 ± 1.0		56			0.97 ± 0.07	4.30
July	0.45 ± 0.02	23.4 ± 0.3		51			1.42 ± 0.07	15.73
August	0.07 ± 0.004	0.04 ± 0.02		1			1.49 ± 0.07	
September	0.22 ± 0.02	8.36 ± 0.46	26.7 ± 1.7	40	72.2 ± 4.6	328	1.71 ± 0.07	
October								
November	0.08 ± 0.02	3.97 ± 0.21	4.90 ± 0.30	50	23.9 ± 1.5	298		
December	2nd milk by middle of April '59							
1959 January			4.51 ± 0.41		37.5 ± 3.4			

• Data reported by station.

MONTHLY FALLOUT COLLECTIONS

Tasmania, Hobart

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'n. in inches
1958 6/13-7/1	0.08 ± 0.02	0.17 ± 0.03		2.2			0.08 ± 0.02	
July	1.07 ± 0.10	0.000 ± 0.004					1.15 ± 0.10	
August	0.20 ± 0.01	6.51 ± 0.42	4.13 ± 1.03	32	8.4 ± 2.1	42	1.35 ± 0.10	
September	0.08 ± 0.02	1.96 ± 0.19	2.00 ± 0.27	24	5.4 ± 0.7	68	1.43 ± 0.10	
October	0.34 ± 0.02	4.69 ± 0.25	2.04 ± 0.21	14	7.3 ± 0.8	21	1.77 ± 0.11	
November	0.29 ± 0.03	4.45 ± 0.31		15				
December			6.80 ± 0.39		45.3 ± 0.3			5.14

MONTHLY FALLOUT COLLECTIONS

Thailand, Bangkok

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1957 March through December							0.38 ± 0.04	
1958 January	0.12 ± 0.01	0.35 ± 0.14		6			0.50 ± 0.04	1.56
February	sample lost in transit							1.56
March	0.04 ± 0.00	0.19 ± 0.02		5			0.54 ± 0.04	0.12
April	0.04 ± 0.03	1.68 ± 0.03		44			0.58 ± 0.05	0.12
May	0.05 ± 0.03	0.93 ± 0.37		17			0.63 ± 0.06	1.56
June	0.17 ± 0.01	13.4 ± 0.1		79			0.80 ± 0.06	7.32
July	0.40 ± 0.02	34.3 ± 1.0		86			1.20 ± 0.06	6.63
August	0.228 ± 0.016	10.1 ± 0.6		44			1.43 ± 0.06	12.48
September	0.04 ± 0.02	1.84 ± 0.33	6.62 ± 0.62	46	17.9 ± 1.7	44.8	1.47 ± 0.07	12.48
October	0.12 ± 0.02	5.82 ± 0.29	13.1 ± 0.7	48	46.8 ± 2.5	390	1.59 ± 0.07	8.97
November	0.02 ± 0.02	1.15 ± 0.53	1.74 ± 0.29	57	6.9 ± 1.2	345	1.61 ± 0.07	0.48
December			3.33 ± 0.72		22.2 ± 4.8			0

• Data reported by station.

* Data reported by station.

MONTHLY FALLOUT COLLECTIONS

Union of South Africa, Durban

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1957 June through December							1.27 ± 0.05	
1958 January	0.02 ± 0.01	< 0.03		< 5			1.29 ± 0.05	9.75
February	0.18 ± 0.01	0.29 ± 0.07		16			1.47 ± 0.05	10.53
March	0.09 ± 0.01	0.19 ± 0.09		2			1.56 ± 0.05	4.68
April	0.46 ± 0.06	< 0.71		< 2			2.02 ± 0.08	11.[illegible]
May	0.91 ± 0.05						2.93 ± 0.10	0.[illegible]
June	0.04 ± 0.003	1.31 ± 0.16		34			2.97 ± 0.10	0.76
July	0.14 ± 0.02	1.59 ± 0.19		4			3.41 ± 0.10	0.78
August	0.02 ± 0.002	0.28 ± 0.02		15			3.43 ± 0.10	0.25
September	0.40 ± 0.02	13.0 ± 0.4	3.65 ± 0.29	32	9.9 ± 0.8	25	3.83 ± 0.10	3.12
October	0.38 ± 0.02	9.89 ± 0.45	6.09 ± 0.54	16	21.8 ± 1.9	57	4.21 ± 0.11	1.17
November	0.60 ± 0.03	8.58 ± 0.31	37.2 ± 0.7	14	181 ± 3	62	4.81 ± 0.11	4.29
December	0.60 ± 0.03	6.81 ± 0.32	5.17 ± 0.33	11	30.4 ± 2	51	5.41 ± 0.11	

MONTHLY FALLOUT COLLECTIONS

Union of South Africa, Pretoria

Sampling Period	millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at Sampling Midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	Cumulative mc Sr^{90} / mi^2	ppt'ns. in* Inches
1957 July through December							0.99 ± 0.03	0.63
1958 January	0.10 ± 0.01	0.29 ± 0.14		29			1.09 ± 0.03	4.91
February	0.06 ± 0.01	0.18 ± 0.05		3			1.15 ± 0.03	1.13
March	0.11 ± 0.00	0.32 ± 0.04		3			1.26 ± 0.03	3.32
April	0.17 ± 0.06	0.50 ± 0.61		3			1.43 ± 0.07	3.39
May	0.49 ± 0.04	----					1.92 ± 0.08	0.92
June	0.02 ± 0.003	0.65 ± 0.02		38			1.94 ± 0.08	0.04
July	0.051 ± 0.004	1.98		39			1.99 ± 0.08	0
August	0.01 ± 0.02	1.94 ± 2.42	3.13 ± 1.00	194 ?	6.4 ± 2.0	640 ?	2.00 ± 0.08	0
September	0.39 ± 0.04	35.5 ± 1.5		60			2.39 ± 0.09	1.86
October	0.86 ± 0.04	28.8 ± 1.0	1.44 ± 0.65	33	5.1 ± 2.3		3.45 ± 0.10	2.34
November	0.36 ± 0.02	6.28 ± 0.33		17			3.81 ± 0.10	4.29
December	2nd milk by middle of April '59							
1959 January								
February	sample not started 1st week April '59							

* Data reported by station.

* Data reported by station.

Strontium 90 in Fallout Collected at Sea

56° 30' N, 51° 00' W (Station "Bravo")

Sampling Period		millicuries per square mile at midpoint of sampling period			Sr^{89}/Sr^{90} at sampling midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	ppt'n. in inches
		Sr^{90}	Sr^{89}	W^{185}				
2-25-58	3-5-58	sample received at HASL but not accounted for						
3-5-58	6-4-58	no samples received at HASL for this period						
6-4,8,10-12	15-17-58	3.23 ± 0.21	37.6 ± 1.3		12			
6-17-58	6-22-58	no samples received at HASL for this period						
6-22-58	7-14-58	0.67 ± 0.02	2.11 ± 0.11					
7-14-58	8-9-58	no samples received at HASL for this period						
8-9-58	8-14-58	0.16 ± 0.09	6.35 ± 0.07		40			
8-14-58	8-25-58	0.27 ± 0.02	4.4 ± 0.2		16			
8-25-58	8-28-58	0.30 ± 0.12	5.00 ± 2.16		17			
8-28-58	9-15-58	0.11 ± 0.03	2.28 ± 0.04	4.14 ± 1.00	21	10.0 ± 2.4	91	
9-16-58	9-27-58	0.01 ± 0.01	(-)0.64 ± 0.45	44.8 ± 2.0	--	128.0 ± 5.7	12,800 †	
9-28-58	10-6-58	0.11 ± 0.01	2.10 ± 0.15	0.57 ± 0.85	19	1.8 ± 2.7	16	
10-6-58	11-4-58	no samples received at HASL for this period						
11-4-58	11-18-58	0.12 ± 0.02	3.63 ± 0.20	1.82 ± 0.30	30	8.2 ± 1.4	68	
11-18-58	11-22-58	no samples received at HASL for this period						
11-22-58	11-25-58	0.09 ± 0.05	4.02 ± 0.70		45			
11-25-58	12-1-58	0.13 ± 0.06	4.41 ± 0.83		34			
12-1-58	12-8-58	no samples received at HASL for this period						
12-8-58	12-28-58	0.13 ± 0.03	5.61 ± 0.36		43			
12-29-58	1-5-59	in process						
1-5-59	1-12-59	no samples received at HASL for this period						
1-12-59	1-20-59	in process		0.45 ± 0.34				
2-20-59	3-3-59	in process						

† Data reported by station.

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Strontium 90 in Fallout Collected at Sea

52° 45' N, 35° 30' W (Station "Charlie")

Sampling Period		millicuries per square mile at midpoint of sampling period Sr^{90}	Sr^{89}	W^{185}	Sr^{89}/Sr^{90} at sampling midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	ppt'n. in inches
12-24-57	1-13-58	0.07 ± 0.07	1.6 ± 0.4		23			
1-14-58	2-1-58	0.11 ± 0.01	1.0 ± 0.2		9			
2-1-58	2-4-48	no samples received at HASL for this period						
(1) 2-4-58	2-8-58	sample lost at HASL						
2-9-58	2-25-58	0.15 ± 0.01	1.7 ± 0.2		11			
(2) 2-25-58	3-5-58	0.13 ± 0.01	1.3 ± 0.3		10			
3-6-58	3-16-58	no samples received at HASL for this period						
3-17-58	4-8-58	0.04 ± 0.01	0.6 ± 0.1		15			
4-8-58	4-29-58	sample received at HASL but not accounted for						
4-29-58	5-20-58	sample received at HASL but not accounted for						
5-20-58	6-7-58	0.06 ± 0.02	1.6 ± 0.3		5			
6-7-58	6-18-58	no samples received at HASL for this period						
6-18-58	6-30-58	0.70 ± 0.04	0.31 ± 0.09		0.4			
6-30-58	7-12-58	no samples received at HASL for this period						
7-12-58	7-13-58	0.04 ± 0.07	0.02 ± 0.01		2			
7-13-58	8-1-58	no samples received at HASL for this period						
8-1-58	8-3-58	0.17 ± 0.01	2.4 ± 0.7		14			
8-3-58	8-8-58	no samples received at HASL for this period						
8-8-58	8-19-58	0.36 ± 0.02	4.96 ± 0.80		14			
8-19-58	9-1-58	0.50 ± 0.03	8.22 ± 0.50		16			
9-1-58	9-23-58	no samples received at HASL for this period						
9-23-58	10-14-58	(-)0.01 ± 0.02	0.97 ± 2.45	2.76 ± 0.53	--	8.9 ± 1.7		
10-14-58	10-24-58	0.19 ± 0.04	6.91 ± 0.55		36			
10-24-58	11-4-58	0.33 ± 0.05	14.1 ± 0.8					
11-4-58	11-24-58	0.21 ± 0.04	7.59 ± 0.35	2.62 ± 0.44	36	12.4 ± 2.1	59	
11-24-58	12-14-58	sample counted						
12-14-58	12-31-58	sample counted		0.09 ± 0.04		0.6 ± 0.3		
1-1-59	1-14-59			1.17 ± 0.63				
1-4-59	1-6-59	no samples received at HASL for this period						
1-6-59	1-25-59	in process						

(1) rinse water used for this collection period - 0.06 ± 0.03 mc Sr^{89}/mi^2 on 5-19-58 and <0.01 mc Sr^{90}/mi^2 (HASL# 7709)
(2) " " " " " " " - <0.03 mc Sr^{89}/mi^2 on 6-12-58 and < 0.02 mc Sr^{90}/mi^2 (HASL# 7776)

Strontium 90 in Fallout Collected at Sea

44° 00' N, 41° 00' W (Station "Delta")

Sampling Period		millicuries per square mile at midpoint of sampling period			Sr^{89}/Sr^{90} at sampling midpoint	mc W^{185} / mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	ppt'n. in inches
		Sr^{90}	Sr^{89}	W^{185}				
6-2-58	6-16-58	0.10 ± 0.05	1.2 ± 0.4		12			
6-16-58	7-7-58	1.46 ± 0.02	10.0 ± 0.4		7			
7-7-58	7-17-58	no samples received at HASL for this period						
7-18-58	7-19-58	0.04 ± 0.01	0.01 ± 0.01		0.3			
7-20-58	8-1-58	no samples received at HASL for this period						
8-1-58	8-19-58	0.27 ± 0.01	4.98 ± 0.09		18			
8-19-58	9-29-58	no samples received at HASL for this period						
9-29-58	10-9-58	0.02 ± 0.02	0.38 ± 0.024	1.56 ± 0.59	19	5.0 ± 1.9	250	
10-10-58	10-12-58	0.01 ± 0.01	0.43 ± 0.79	2.26 ± 0.67	43	8.1 ± 2.4	810	
10-13-58	10-15-58	0.04 ± 0.02	2.71 ± 0.33	14.1 ± 0.6	68	48.6 ± 2.1	1215	
10-16-58	10-20-58	0.03 ± 0.02	2.41 ± 0.23	1.56 ± 0.4	68	5.8 ± 1.5	193	
10-21-58	10-31-58	0.35 ± 0.03	45.6 ± 1.5		130			
11-1-58	11-9-58	0.15 ± 0.02	5.05 ± 0.30	26.9 ± 1.8	32			
11-10-58	11-21-58	0.37 ± 0.04	11.1 ± 0.4	2.20 ± 0.33	30	10.5 ± 1.6	28	
11-22-58	11-26-58	0.21 ± 0.03	14.4 ± 0.5	3.08 ± 0.40	68	16.2 ± 2.1	77	
11-27-58	12-1-58	0.35 ± 0.06	10.2 ± 0.5	3.13 ± 0.26	9	17.4 ± 1.4	50	
12-2-58	12-8-58			3.15 ± 0.82				
12-9-58	12-17-58	sample counted						
12-18-58	12-22-58	0.07 ± 0.02	2.87 ± 0.24	0.34 ± 0.48	41	2.3 ± 3.2	33	
12-22-58	1-4-59	sample counted						
1-5-59	1-12-59			0.09 ± 0.22				
1-12-59	1-17-59	in process						
1-18-59	2-3-59			1.42 ± 0.64				
2-3-59	2-11-59	no samples received at HASL for this period						
2-11-59	2-23-59	in process						

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Strontium 90 in Fallout Collected at Sea

35° 00' N, 48° 00' W (Station "Echo")

Sampling Period		millicuries per square mile at midpoint of sampling period			Sr^{89}/Sr^{90} at sampling midpoint	mc W^{185}/mi^2 on 6-1-58	W^{185}/Sr^{90} on 6-1-58	ppt'n. in inches
		Sr^{90}	Sr^{89}	W^{185}				
5-2-58	5-24-58	sample received at HASL but not accounted for						
5-24-58	6-13-58	0.11 ± 0.05	0.76 ± 0.14		7			
6-14-58	7-5-58	0.07 ± 0.01	0.32 ± 0.05		5			
7-5-58	7-9-58	0.40 ± 0.02	3.5 ± 0.07		9			
7-9-58	7-17-58	no samples received at HASL during this period						
7-17-58	7-24-58	0.11 ± 0.01	3.9 ± 0.3		4			
7-24-58	8-16-58	no samples received at HASL during this period						
8-16-58	9-7-58	0.05 ± 0.01	2.1 ± 0.4		39			
9-7-58	9-13-58	0.07 ± 0.04	3.58 ± 0.62	1.21 ± 0.71	51	17		
9-13-58	9-15-58	no samples received at HASL during this period						
9-15-58	9-26-58	0.05 ± 0.04	1.36 ± 0.75	0.98 ± 0.58	27	20		
9-26-58	9-30-58	no samples received at HASL during this period						
9-30-58	10-18-58	0.19 ± 0.03	6.36 ± 0.35	1.19 ± 2.25	33			
10-18-58	10-22-58	0.07 ± 0.03	4.08 ± 0.61	7.66 ± 0.98	58	109		
10-22-58	10-31-58	0.43 ± 0.04	42.0 ± 1.7		93			
11-1-58	11-3-58	no samples received at HASL during this period						
11-3-58	11-7-58	0.15 ± 0.02	7.78 ± 0.26	2.24 ± 0.35	52	9.7 ± 1.5	65	
11-8-58	11-29-58	0.10 ± 0.02	5.69 ± 0.30	0.74 ± 0.34	57	3.5 ± 1.6		
11-30-58	12-20-58	no samples received at HASL during this period						
12-20-58	12-21-58	sample received at HASL but not accounted for						
12-21-58	12-23-58	no samples received at HASL during this period						
12-23-58	12-26-58	in process						
12-26-58	12-29-58	no samples received at HASL during this period						
12-29-58	1-4-59	in process		0.66 ± 0.33				
1-4-59	1-9-59	in process						

Table 6 - Cont'd.

Table 6 - Cont'd.

PRECIPITATION COLLECTIONS - Richmond, California - Cont'd.

Sampling Period from	to	At Midpoint of Sampling Period: mc Sr^{90}/mi^2	mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958									
7-18	7-25	0.0138 ± 0.0005	0.254 ± 0.002	0.65 ± 0.01		18.4	47.1	5.80 ± 0.34	dry
		0.0138 ± 0.0005	0.252 ± 0.002	0.45 ± 0.01		18.2	32.6		dry
7-25	8-1	0.081 ± 0.004	0.60 ± 0.01	0.570 ± 0.005		7.4	7.0	5.88 ± 0.34	dry
		0.069 ± 0.003	0.63 ± 0.01	0.660 ± 0.005		9.1	9.5		dry
8-1	8-8	0.007 ± 0.001	0.087 ± 0.004	0.158 ± 0.002		12.4	22.5	5.89 ± 0.34	dry
		0.005 ± 0.001	0.082 ± 0.004	0.123 ± 0.005		16.4	26.4		dry
8-8	8-15	0.024 ± 0.002	0.030 ± 0.006	0.171 ± 0.005	0.029	1.2	7.1	5.92 ± 0.34	dry
		0.044 ± 0.003	0.032 ± 0.005	0.158 ± 0.005	lost	0.7	3.6		dry
8-15	8-22	0.036 ± 0.002	0.338 ± 0.005	0.46 ± 0.02	0.64 ± 0.01	9.4	12.8	5.96 ± 0.34	dry
		0.044 ± 0.004	0.269 ± 0.010	0.48 ± 0.02	0.65 ± 0.02	6.1	10.9		dry
8-22	8-29	0.005 ± 0.001	0.088 ± 0.005	0.074 ± 0.002		17.6	14.8	5.97 ± 0.34	dry
		0.005 ± 0.001	0.085 ± 0.004	0.064 ± 0.002		17.0	16.8		dry
8-29	9-6	<0.001	0.087 ± 0.002	0.064 ± 0.002	0.583 ± 0.013			5.97 ± 0.34	dry
		0.001 ± 0.001	0.089 ± 0.002	0.118 ± 0.002	0.142 ± 0.007				dry
9-6	9-13	0.028 ± 0.001	0.63 ± 0.02	<0.64	1.55 ± 0.05	22.5	<22.8	5.99 ± 0.34	dry
		0.021 ± 0.001	0.64 ± 0.02	<0.49	1.67 ± 0.06	30.4	<23.3		dry
9-13	9-20	0.006 ± 0.001	0.023 ± 0.002	0.024 ± 0.001	0.34 ± 0.02	3.8	4.0	6.00 ± 0.34	dry
		0.005 ± 0.001	0.029 ± 0.002	0.031 ± 0.001	0.35 ± 0.02	5.8	6.2		dry
9-20	9-23	0.016 ± 0.001	0.25 ± 0.01	0.09 ± 0.01	0.85 ± 0.02	15.6	5.6	6.02 ± 0.34	0.05
		0.014 ± 0.001	0.26 ± 0.01	0.09 ± 0.01	0.76 ± 0.02	18.5	6.4		0.05
9-23	9-30	0.002 ± 0.001	0.030 ± 0.002	0.016 ± 0.001	0.087 ± 0.002			6.02 ± 0.34	dry
		0.001 ± 0.001	0.026 ± 0.001	0.017	0.148 ± 0.005				dry
9-30	10-7	0.006 ± 0.001	0.028 ± 0.001	0.14 ± 0.01	0.24 ± 0.01	4.7	23	6.02 ± 0.34	dry
		0.004 ± 0.001	0.026 ± 0.001	0.13 ± 0.01	0.28 ± 0.01	6.5	32		dry

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Table 6 - Cont'd.

PRECIPITATION COLLECTIONS - Richmond, California - Cont'd.

Sampling from	Period to	At Midpoint of Sampling Period: mc Sr^{90}/mi^2	mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958									
10-7	10-14	0.003 ± 0.001	0.029 ± 0.002	0.028 ± 0.002	0.44 ± 0.01	10	9	6.02	dry
		0.003 ± 0.001	0.074 ± 0.018	<0.026	0.37 ± 0.01	25			dry
10-14	10-20	0.02 ± 0.01	0.60 ± 0.01	1.47 ± 0.06	0.40 ± 0.01	30	74	6.04	0.17
		0.02 ± 0.01	0.54 ± 0.01	1.10 ± 0.03	0.54 ± 0.02	27	55		0.17
10-20	10-27	0.003 ± 0.001	0.075 ± 0.002	0.76 ± 0.01	0.220 ± 0.005	25	253	6.05	dry
		0.005 ± 0.001	0.086 ± 0.002	1.30 ± 0.02	0.204 ± 0.005	17	260		dry
10-27	11-3	0.004 ± 0.001	0.105 ± 0.002	1.33 ± 0.01	0.41 ± 0.02	26	332	6.05	dry
		0.007 ± 0.001	0.088 ± 0.002	1.63 ± 0.03	lost	12	232		dry
11-3	11-10	0.005 ± 0.003	0.36 ± 0.01	0.73 ± 0.03	0.243 ± 0.002	72	146	6.06	0.04
				0.92 ± 0.03	0.243 ± 0.002				0.04
11-10	11-17	0.008 ± 0.003	0.26 ± 0.01	0.73 ± 0.03	0.26 ± 0.01	32	91	6.07	dry
		0.019 ± 0.006	0.24 ± 0.01	0.42 ± 0.02	0.25 ± 0.01	13	22		dry
11-17	11-24	0.014 ± 0.001	0.128 ± 0.005	0.338 ± 0.005	0.233 ± 0.012	9	24	6.08	dry
		0.012 ± 0.001	0.105 ± 0.004	0.182 ± 0.005	0.174 ± 0.011	9	15		dry
11-24	12-1	0.008 ± 0.001	0.156 ± 0.004	0.268 ± 0.005	0.238 ± 0.002	20	34	6.09	trace
		0.013 ± 0.001	0.151 ± 0.005	0.248 ± 0.010	0.274 ± 0.002	12	19		trace
12-1	12-8	0.002 ± 0.001	0.080 ± 0.006	0.095 ± 0.002	0.14 ± 0.01	40	48	6.10	dry
		0.005 ± 0.001	0.124 ± 0.003	0.087 ± 0.002	0.16 ± 0.01	25	17		dry
12-8	12-15	0.001 ± 0.001	0.071 ± 0.002	0.077 ± 0.002	0.13 ± 0.01			6.10	dry
		0.005 ± 0.001	0.051 ± 0.002	0.046 ± 0.002	0.12 ± 0.01	10	9		dry
12-15	12-22	0.087 ± 0.006	2.39 ± 0.04	1.44 ± 0.03	0.63 ± 0.02	27	16	6.18	0.62
		0.089 ± 0.007	2.73 ± 0.05	1.52 ± 0.03	1.16 ± 0.04	31	17		0.62

Table 6 - Cont'd.

PRECIPITATION COLLECTIONS - Richmond, California - Cont'd.

Sampling from	Period to	At Midpoint of Sampling Period: mc Sr^{90}/mi^2	mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958									
12-22	12-29	0.190 ± 0.012	6.60 ± 0.06	2.5 ± 0.1	0.93 ± 0.02	35	13	6.36	1.15
		0.165 ± 0.011	6.34 ± 0.06	2.7 ± 0.1	1.04 ± 0.02	38	16		1.15
12-29	1-7-59	0.629 ± 0.021	25.8 ± 0.2	7.54 ± 0.12	3.99 ± 0.15	41	12	7.01	1.68
		0.665 ± 0.021	24.4 ± 0.2	7.88 ± 0.13	4.40 ± 0.17	37	12		1.68
1959									
1-7	1-13	0.42 ± 0.04	15.8 ± 0.1	3.89 ± 0.08	2.42 ± 0.08	38	9	7.42	2.01
		0.39 ± 0.01	15.8 ± 0.1	4.19 ± 0.05	2.68 ± 0.10	40	11		2.01
1-13	1-20	0.021 ± 0.001	0.320 ± 0.016	0.152 ± 0.005	1.34 ± 0.05	15	7	7.44	dry
		0.021 ± 0.002	0.306 ± 0.016	0.218 ± 0.006	1.22 ± 0.05	14	10		dry
1-20	1-26	0.259 ± 0.009	7.22 ± 0.04	1.09 ± 0.04	2.94 ± 0.06	28	4	7.69	0.54
		0.240 ± 0.008	7.14 ± 0.04	1.10 ± 0.04	3.76 ± 0.07	30	4		0.54
1-26	1-28	0.065 ± 0.008	1.09 ± 0.02	0.125 ± 0.005	0.263 ± 0.013	17	2	7.75	0.19
		0.050 ± 0.007	1.09 ± 0.02	0.130 ± 0.005	0.214 ± 0.011	22	3		0.19
1-28	2-4	0.034 ± 0.002	0.429 ± 0.020	0.102 ± 0.002	1.87 ± 0.08	13	3	7.78	trace
		0.031 ± 0.002	0.494 ± 0.023	0.114 ± 0.002	1.75 ± 0.08	16	4		trace
2-4	2-9	0.008 ± 0.001	0.058 ± 0.003	<0.011	0.167 ± 0.008	7		7.79	dry
		0.005 ± 0.001	0.061 ± 0.002	<0.010	1.145 ± 0.007	12			dry

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Table 4

PRECIPITATION COLLECTIONS - Pittsburgh, Pennsylvania

Collector Area: 2.58 ft^2

Sampling Period from	to	At End of Sampling Period: mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc Sr^{90}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958								
12-29-57	1-2	0.49 ± 0.06	0.12 ± 0.03	0.051 ± 0.003	9.7	2.4	23.88 ± 0.17	0.13
		0.49 ± 0.10	0.06 ± 0.02	0.052 ± 0.004	9.4	1.2		
1-2	1-3	≤0.02	≤0.005	0.008 ± 0.002			---	trace
		≤0.03	≤0.007	0.006 ± 0.002				
1-3	1-8	0.16 ± 0.02	0.11 ± 0.01	0.014 ± 0.003	11	7.9	23.90 ± 0.17	0.04
		0.18 ± 0.03	0.15 ± 0.02	0.015 ± 0.003	13	10		
1-8	1-16	1.02 ± 0.15	≤0.04	0.069 ± 0.006	15		23.97 ± 0.17	1.61
		0.98 ± 0.10	≤0.06	0.066 ± 0.004	15			
1-16	1-18	0.13 ± 0.02	0.05 ± 0.01	0.014 ± 0.004	9.6	3.8	23.98 ± 0.17	0.01
		0.13 ± 0.03	0.05 ± 0.01	≤0.008				
1-18	1-23	2.00 ± 0.19	0.17 ± 0.04	0.148 ± 0.008	13	1.2	24.13 ± 0.17	0.48
		2.14 ± 0.39	0.09 ± 0.03	0.139 ± 0.008	15	0.6		
1-23	1-26	2.82 ± 0.39	0.29 ± 0.03	0.239 ± 0.011	12	1.2	24.35 ± 0.17	0.90
		3.07 ± 0.34	0.28 ± 0.03	0.200 ± 0.011	15	1.4		
1-26	1-28	0.44 ± 0.04	0.10 ± 0.01	0.031 ± 0.002	14	3.1	24.38 ± 0.17	0.15
		0.49 ± 0.06	0.10 ± 0.01	0.035 ± 0.004	14	2.7		
1-28	1-31	0.39 ± 0.03	≤0.01	0.030 ± 0.003	13		24.41 ± 0.17	0.08
		0.42 ± 0.04	0.05 ± 0.02	0.032 ± 0.002	13	1.7		
1-31	2-3	0.18 ± 0.02	0.02 ± 0.01	0.023 ± 0.002	7.6	0.9	24.43 ± 0.17	0.04
		0.18 ± 0.03	≤0.01	0.020 ± 0.002	9.2			

		0.18 ± 0.03	≤0.01	0.020 ± 0.002	9.2		24.43 ± 0.17	0.04

Table 4 - Cont'd.

PRECIPITATION COLLECTIONS - Pittsburgh, Pennsylvania - Cont'd.

Collector Area: 2.58 ft^2

Sampling Period from	to	At End of Sampling Period: mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc Sr^{90}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958								
2-3	2-6	1.22 ± 0.10 0.83 ± 0.15	0.11 ± 0.02 0.07 ± 0.02	0.106 ± 0.005 0.075 ± 0.004	12 11	1.0 0.9	24.52 ± 0.17	0.12
2-6	2-8	1.36 ± 0.29 1.12 ± 0.34	0.07 ± 0.03 ≤0.04	0.105 ± 0.005 0.115 ± 0.006	13 9.7	0.6	24.63 ± 0.17	0.21
2-8	2-17	0.29 ± 0.03 0.32 ± 0.02	≤0.05 ≤0.03	0.028 ± 0.003 0.031 ± 0.002	10 10		24.66 ± 0.17	0.24
2-17	2-24	0.25 ± 0.04 0.24 ± 0.05	≤0.02 ≤0.02	0.030 ± 0.003 0.028 ± 0.003	8.5 8.6		24.69 ± 0.17	dry
2-24	2-27	0.73 ± 0.15 1.02 ± 0.10	≤0.02 ≤0.01	0.065 ± 0.005 0.087 ± 0.004	11 12		24.77 ± 0.17	0.32
2-27	3-1	0.21 ± 0.02 0.23 ± 0.06	≤0.004 ≤0.004	0.014 ± 0.002 0.020 ± 0.002	14 11		24.78 ± 0.17	0.07
3-1	3-10	0.29 ± 0.02 0.26 ± 0.04	≤0.04 ≤0.02	0.033 ± 0.003 0.020 ± 0.003	8.8 8.5		24.82 ± 0.17	dry
3-10	3-15	1.75 ± 0.29 1.61 ± 0.29	0.18 ± 0.04 0.16 ± 0.03	0.166 ± 0.012 0.145 ± 0.014	10 11	1.1 1.1	24.97 ± 0.17	0.45
3-15	3-18	0.13 ± 0.02 0.15 ± 0.02	0.30 ± 0.07 0.72 ± 0.07	0.018 ± 0.003 0.014 ± 0.004	7.2 11	1.7 5.3	24.99 ± 0.17	0.12
3-18	3-22	0.85 ± 0.07 0.92 ± 0.10	0.51 ± 0.07 0.81 ± 0.09	0.098 ± 0.005 0.096 ± 0.005	8.7 9.6	5.2 8.4	25.08 ± 0.17	0.42

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Table 4 - Cont'd.

PRECIPITATION COLLECTIONS - Pittsburgh, Pennsylvania - Cont'd.

Collector Area: 2.58 ft^2

Sampling Period from	to	mc Sr^{89}/mi^2 at End of Sampling Period	mc Ba^{140}/mi^2 at End of Sampling Period	mc Sr^{90}/mi^2 at End of Sampling Period	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	Ppt'n. in inches
1958								
3-22	3-26	1.36 ± 0.24 1.51 ± 0.19	0.70 ± 0.08 0.75 ± 0.08	0.150 ± 0.008 0.150 ± 0.008	9.1 10	4.7 5.0	25.23 ± 0.17	0.70
3-26	4-2	0.92 ± 0.10 1.26 ± 0.12	1.51 ± 0.34 1.41 ± 0.12	0.050 ± 0.003 0.053 ± 0.004	18 24	30 27	25.29 ± 0.17	
4-2	4-6	1.22 ± 0.15 0.97 ± 0.15	1.61 ± 0.15 1.26 ± 0.12	0.093 ± 0.005 0.068 ± 0.004	13 14	17 19	25.37 ± 0.17	
4-6	4-8	5.25 ± 0.49 5.20 ± 0.39	6.01 ± 0.49 5.84 ± 0.44	0.34 ± 0.02 0.33 ± 0.02	15 16	18 18	25.71 ± 0.17	
4-8	4-12	6.01 ± 0.68 6.04 ± 0.63	5.79 ± 0.49 5.70 ± 0.39	0.50 ± 0.03 0.52 ± 0.03	14 12	12 11	26.22 ± 0.17	
4-12	4-19	0.21 ± 0.04 0.14 ± 0.02	0.85 ± 0.07 0.40 ± 0.03	0.012 ± 0.002 0.014 ± 0.002	16 10	67 30	26.23 ± 0.17	
4-19	4-22	3.31 ± 0.49 3.46 ± 0.58	2.14 ± 0.15 2.43 ± 0.19	0.288 ± 0.021 0.219 ± 0.011	12 16	7.7 11	26.48 ± 0.17	
4-22	4-24	0.34 ± 0.07 0.35 ± 0.08	0.26 ± 0.02 0.20 ± 0.02	0.031 ± 0.003 0.033 ± 0.004	11 11	8.6 6.3	26.52 ± 0.17	
4-24	4-28	2.29 ± 0.21 2.43 ± 0.29	1.16 ± 0.08 1.43 ± 0.12	0.206 ± 0.012 0.209 ± 0.012	11 12	5.7 6.8	26.72 ± 0.17	
4-28	4-29	4.58 ± 0.79 3.89 ± 0.88	1.44 ± 0.12 1.41 ± 0.13	0.35 ± 0.02 0.38 ± 0.02	13 10	4.2 3.7	27.09 ± 0.18	

Table 4 - Cont'd.

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Table 4 - Cont'd.

PRECIPITATION COLLECTIONS - Pittsburgh, Pennsylvania - Cont'd.

Collection Area: 2.58 ft²

Sampling Period from	Sampling Period to	At Midpoint of Sampling Period: mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	mc Sr^{90}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90} mi^2	ppt'n. in inches
1958									
4-29	5-4 *	4.77 ± 0.44 4.29 ± 0.34	1.23 ± 0.16 ---	<0.172 <0.061	0.38 ± 0.02 0.40 ± 0.02	12.6 10.7	3.2 --	27.46 ± 0.18	1.5 1.5
5-4	5-5	1.20 ± 0.12 1.17 ± 0.10	0.35 ± 0.04 ---	<0.487 <0.070	0.092 ± 0.006 0.086 ± 0.005	13.0 13.6	3.9 --	27.55 ± 0.18	0.20 0.20
5-5	5-8	6.57 ± 0.58 6.14 ± 0.49	1.70 ± 0.19 ---	<0.557 <0.103	0.42 ± 0.02 0.41 ± 0.02	15.6 15.0	4.0 --	27.96 ± 0.18	1.09 1.09
5-8	5-10	2.29 ± 0.20 2.58 ± 0.19	0.64 ± 0.10 ---	<0.061 <0.061	0.195 ± 0.015 0.185 ± 0.012	11.7 13.9	3.3 --	28.15 ± 0.18	0.23 0.23
5-10	5-13	0.34 ± 0.11 0.24 ± 0.02	0.06 ± 0.02 ---	<0.139 <0.139	0.024 ± 0.002 0.013 ± 0.002	14.2 18.5	2.5 --	28.17 ± 0.18	-- --
5-13	5-17	4.33 ± 0.58 3.74 ± 0.39	--- ---	<0.054 <0.069	0.42 ± 0.02 0.33 ± 0.02	10.3 11.3	-- --	28.55 ± 0.18	0.21
5-17	5-19	4.77 ± 0.44 4.29 ± 0.34	--- ---	<0.041 <0.149	0.195 ± 0.02 0.151 ± 0.01	24.5 28.4	-- --	28.72 ± 0.18	trace trace
5-19	5-24	1.20 ± 0.12 1.17 ± 0.09	--- ---	<0.042 <0.060	0.41 ± 0.02 0.40 ± 0.04	2.9 2.9	-- --	29.12 ± 0.18	0.23 0.23
5-24	5-28	1.98 ± 0.15 2.07 ± 0.12	0.91 ± 0.20 0.49 ± 0.15	<0.067 <0.944	0.151 ± 0.01 0.199 ± 0.02	1.3 1.0	6.0 2.5	29.30 ± 0.18	0.41 0.41
5-28	6-2	5.1 ± 0.6 3.6 ± 0.3	3.3 ± 0.3 4.8 ± 1.2	<0.93 2.12 ± 0.35	0.253 ± 0.015 0.224 ± 0.025	20 16	13 21	29.54 ± 0.19	0.72 0.72
6-2	6-6	1.34 ± 0.13 0.92 ± 0.12	1.0 ± 0.2 ---	1.05 ± 0.24 0.93 ± 0.18	0.061 ± 0.009 0.043 ± 0.008	22 21	16 lost	29.59 ± 0.19	0.10 0.10
6-6	6-10	1.08 ± 0.12 ---	2.3 ± 0.3 ---	0.61 ± 0.2	0.079 ± 0.006 lost	14 lost	29 lost	29.67 ± 0.19	0.11 0.11
6-10	6-13	2.16 ± 0.16 2.53 ± 0.16	--- ---	0.62 ± 0.16 0.72 ± 0.22	0.127 ± 0.010 0.131 ± 0.010	19 19	lost lost	29.80 ± 0.19	0.22 0.22
6-13	6-19	2.07 ± 0.18 2.66 ± 0.16	2.7 ± 0.4 2.9 ± 0.4	0.49 ± 0.20 0.52 ± 0.21	0.224 ± 0.018 0.244 ± 0.021	9.2 11	12 12	30.03 ± 0.19	0.70 0.70
6-19	6-24	2.58 ± 0.20 2.45 ± 0.20	1.05 ± 0.15 0.70 ± 0.10	1.06 ± 0.23 0.42 ± 0.17	0.210 ± 0.010 0.188 ± 0.010	12 13	5.0 3.7	30.23 ± 0.19	0.65 0.62

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Table 4 - Cont'd.

PRECIPITATION COLLECTIONS - Pittsburgh, Pennsylvania - Cont'd.

Collector Area: 2.58 ft^2

Sampling Period from	to	At Midpoint of Sampling Period: mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	mc Sr^{90}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958 6-20	6-22	2.20 ± 0.20	<0.5	0.73 ± 0.17	0.175 ± 0.010	12	<2.8	30.41 ± 0.19	0.16
		1.93 ± 0.18	<0.3	<0.23	0.194 ± 0.015	9.9	<1.5		0.16
6-22	6-23	1.00 ± 0.12	0.35 ± 0.15	<0.28	0.106 ± 0.006	9.4	3.3	30.54 ± 0.19	0.12
		1.29 ± 0.10	<0.2	<0.160	0.148 ± 0.010	8.7	<1.4		0.12
6-23	6-24	0.55 ± 0.09	<0.3	0.48 ± 0.17	0.062 ± 0.003	8.9	<4.8	30.61 ± 0.19	0.05
		0.64 ± 0.06	<0.3	0.49 ± 0.16	0.080 ± 0.006	8.0	<3.8		0.05
6-24	6-26	2.20 ± 0.20	2.6 ± 0.3	<0.68	0.114 ± 0.006	19	23	30.73 ± 0.19	0.17
		2.59 ± 0.30	2.3 ± 0.3	<0.38	0.117 ± 0.007	22	20		0.17
6-26	7-3	0.22 ± 0.03	<0.10	<0.38	0.019 ± 0.003	12	<5.3	30.75 ± 0.19	dry
		0.34 ± 0.04	0.16 ± 0.06	<0.37	0.026 ± 0.003	13	6.1		dry
7-3	7-7	6.8 ± 0.5	10.3 ± 0.8	2.56 ± 0.37	0.296 ± 0.030	23	35	31.04 ± 0.19	1.15
		8.3 ± 1.0	11.0 ± 0.8	3.04 ± 0.37	0.292 ± 0.020	28	38		1.15
7-7	7-8	0.27 ± 0.04	<0.12	<0.57	0.013 ± 0.002	21	<9.2	31.06 ± 0.19	0.2
		0.35 ± 0.04	0.61 ± 0.10		0.016 ± 0.003	22	38		0.2
7-8	7-11	9.7 ± 0.7	16.0 ± 1.5	1.40 ± 0.21	0.244 ± 0.015	39.8	65.6	31.31 ± 0.24	1.25
		14.6 ± 1.4	24.5 ± 2.0	1.57 ± 0.24	0.258 ± 0.015	56.6	95.0		1.25
7-11	7-12	2.44 ± 0.24	4.3 ± 0.4	0.81 ± 0.22	0.067 ± 0.010	36.4	64.2	31.37 ± 0.24	0.26
		2.56 ± 0.20	4.2 ± 0.4	0.73 ± 0.17	0.060 ± 0.004	42.7	70.0		0.26
7-12	7-14	4.2 ± 0.4	6.1 ± 0.4	2.19 ± 0.37	0.097 ± 0.007	43	63	31.46 ± 0.25	0.28
		4.0 ± 0.4	6.1 ± 0.5	2.07 ± 0.24	0.076 ± 0.006	53	80		0.28
7-14	7-15	5.8 ± 0.6	6.3 ± 0.5	4.16 ± 0.49	0.132 ± 0.007	43	48	31.58 ± 0.25	0.78
		6.2 ± 0.6	8.9 ± 0.7	4.63 ± 0.49	0.111 ± 0.006	56	80		0.78
7-15	7-16	4.5 ± 0.4	7.1 ± 0.5	2.02 ± 0.37	0.056 ± 0.004	80	127	31.64 ± 0.25	0.29
		3.9 ± 0.4	7.3 ± 0.5	2.61 ± 0.37	0.058 ± 0.003	67	126		0.29
7-16	7-21	2.42 ± 0.22	7.9 ± 1.5	2.73 ± 0.37	0.048 ± 0.004	50.4	164.6	31.69 ± 0.25	trace
		1.87 ± 0.18	4.8 ± 0.6	2.38 ± 0.37	0.056 ± 0.004	33.4	85.7		trace
7-21	7-22	11.8 ± 1.0	15.3 ± 1.4	11.02 ± 1.04	0.190 ± 0.010	62.1	80.5	31.89 ± 0.25	0.88
		12.5 ± 1.4	11.7 ± 1.0	14.37 ± 1.22	0.200 ± 0.010	62.5	58.5		0.88
7-22	7-23	3.2 ± 0.3	3.6 ± 0.3	3.54 ± 0.44	0.055 ± 0.003	58	65	31.94 ± 0.25	0.35
		3.1 ± 0.3	3.6 ± 0.3	4.17 ± 0.58	0.060 ± 0.003	52	60		0.35

Table 4 - Cont'd.

Table 4 - Cont'd.

PRECIPITATION COLLECTIONS - Pittsburgh, Pennsylvania - Cont'd.

Collector Area: 2.58 ft^2

Sampling Period From	to	At Midpoint of Sampling Period mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	mc Sr^{90}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958									
7-23	7-24	4.2 ± 0.5	2.5 ± 0.2	6.06 ± 0.65	0.150 ± 0.008	28	17	32.11 ± 0.25	0.40
		4.4 ± 0.5	3.7 ± 0.3	6.23 ± 0.57	0.180 ± 0.010	24	20		0.40
7-24	7-25	0.58 ± 0.06	0.35 ± 0.04	0.66 ± 0.16	0.026 ± 0.003	22	13	32.13 ± 0.25	0.03
		0.62 ± 0.06	0.40 ± 0.08	1.97 ± 0.22	0.019 ± 0.002	33	21		0.03
7-25	7-29	11.5 ± 0.9	11.5 ± 0.8	0.53 ± 0.16	0.173 ± 0.010	66	66	32.30 ± 0.25	1.40
		11.2 ± 0.8	12.7 ± 0.8	0.52 ± 0.16	0.159 ± 0.008	70	80		1.40
7-29	7-30	1.86 ± 0.16	2.05 ± 0.18	1.52 ± 0.30	0.057 ± 0.005	32.6	36.0	32.36 ± 0.25	0.25
		2.08 ± 0.20	2.50 ± 0.23	1.95 ± 0.32	0.076 ± 0.010	27.4	33.0		0.25
7-30	7-31	7.2 ± 0.6	6.0 ± 0.4	5.28 ± 0.52	0.205 ± 0.010	35	29	32.56 ± 0.25	1.13
		5.9 ± 0.5	6.8 ± 0.5	6.06 ± 0.54	0.189 ± 0.010	31	36		1.13
7-31	8-1	2.56 ± 0.24	2.4 ± 0.2	1.43 ± 0.16	0.041 ± 0.003	62	58	32.60 ± 0.25	0.37
		2.41 ± 0.20	2.9 ± 0.3	1.49 ± 0.17	0.039 ± 0.003	62	74		0.37
8-1	8-3	5.5 ± 0.4	4.7 ± 0.3	6.07 ± 0.38	0.149 ± 0.007	37	32	32.74 ± 0.25	1.88
		5.5 ± 0.5	4.7 ± 0.4	3.96 ± 0.26	0.131 ± 0.007	42	36		1.88
8-3	8-7	1.89 ± 0.18	1.76 ± 0.16	1.45 ± 0.18	0.076 ± 0.008	24.9	23.2	32.82 ± 0.25	0.17
		2.18 ± 0.23	1.82 ± 0.16	1.01 ± 0.16	0.078 ± 0.005	27.9	23.3		0.17
8-7	8-8	7.4 ± 0.5	4.5 ± 0.4	4.38 ± 0.24	0.34 ± 0.02	21.8	13.2	33.15 ± 0.25	1.17
		7.0 ± 0.6	4.3 ± 0.4	2.72 ± 0.19	0.32 ± 0.02	21.9	13.4		1.17
8-8	8-12	2.66 ± 0.28	2.68 ± 0.22	1.48 ± 0.17	0.061 ± 0.004	43.6	44.0	33.21 ± 0.25	0.09
		2.86 ± 0.28	2.68 ± 0.24	0.96 ± 0.15	0.063 ± 0.005	45.4	42.5		0.09
8-12	8-14	0.77 ± 0.15	0.64 ± 0.07	0.42 ± 0.13	0.022 ± 0.005	35.0	29.1	33.23 ± 0.25	0.04
		0.79 ± 0.10	0.61 ± 0.08	<0.24	0.018 ± 0.005	43.9	33.9		0.04
8-14	8-15	2.62 ± 0.35	1.91 ± 0.16	0.35 ± 0.13	0.078 ± 0.006	33.6	24.5	33.30 ± 0.25	0.13
		2.36 ± 0.30	2.05 ± 0.17	lost	0.063 ± 0.005	34.2	29.7		0.13
8-15	8-16	3.64 ± 0.32	2.17 ± 0.21	0.34 ± 0.14	0.098 ± 0.008	37.1	22.1	33.40 ± 0.25	0.17
		3.79 ± 0.30	1.90 ± 0.23	0.55 ± 0.18	0.097 ± 0.008	39.1	19.6		0.17
8-16	8-17	0.16 ± 0.07	0.19 ± 0.10	0.58 ± 0.13	0.012 ± 0.005	13.3	15.8	33.41 ± 0.25	trace
		0.24 ± 0.03	< 0.12	<0.24	0.015 ± 0.004	16.0	<100		trace
8-17	8-21	1.92 ± 0.18	1.32 ± 0.20	0.96 ± 0.17	0.067 ± 0.004	28.7	19.7	33.48 ± 0.25	0.12
		1.42 ± 0.12	0.73 ± 0.15	1.29 ± 0.17	0.061 ± 0.005	23.3	12.0		0.12
8-21	8-22	1.53 ± 0.20	1.07 ± 0.16	1.34 ± 0.15	0.067 ± 0.004	22.8	16.0	33.54 ± 0.25	0.11
		1.71 ± 0.12	1.8 ± 0.9	0.67 ± 0.15	0.062 ± 0.004	27.6	29.0		0.11

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Table 4 - Cont'd.

PRECIPITATION COLLECTIONS - Pittsburgh, Pennsylvania - Cont'd.

Collector Area: 2.58 ft^2

Sampling Period from	to	At Midpoint of Sampling Period: mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	mc Sr^{90}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958 8-22	8-25	4.48 ± 0.30	2.9 ± 1.1	1.71 ± 0.15	0.151 ± 0.055	29.7	19.2	33.68 ± 0.25	0.95
		3.94 ± 0.75	3.4 ± 1.1	1.73 ± 0.15	0.131 ± 0.012	30.1	26.0		0.95
8-25	9-2	3.02 ± 0.40	lost	4.15 ± 0.25	0.123 ± 0.022	24.6	—	33.80 ± 0.25	0.13
		3.41 ± 0.35	lost	1.61 ± 0.15	0.119 ± 0.024	28.7	—		0.13
9-2	9-25	3.08 ± 0.15	1.4 ± 0.2	2.26 ± 0.10	0.115 ± 0.007	26.8	12.2	33.93 ± 0.25	0.64
		3.69 ± 0.28	1.9 ± 0.6	2.77 ± 0.15	0.131 ± 0.006	28.2	14.5		0.64
9-5	9-7	1.76 ± 0.10	0.9 ± 0.3	1.63 ± 0.16	0.068 ± 0.007	25.9	13.2	33.99 ± 0.25	0.44
		1.82 ± 0.10	1.3 ± 0.3	2.42 ± 0.18	0.055 ± 0.004	33.1	23.6		0.44
9-7	9-14	0.20 ± 0.06	lost	0.43 ± 0.08	<0.020	>10	—	34.00 ± 0.25	0
		0.23 ± 0.08	lost	0.75 ± 0.15	<0.010	>23	—		0
9-14	9-16	1.06 ± 0.09	0.30 ± 0.10	1.29 ± 0.13	0.040 ± 0.004	26.5	7.5	34.05 ± 0.25	0.20
		1.11 ± 0.07	0.32 ± 0.11	1.77 ± 0.14	0.058 ± 0.005	19.1	5.5		0.20
9-16	9-17	1.28 ± 0.08	0.37 ± 0.10	1.03 ± 0.12	0.041 ± 0.003	32.0	9.0	34.10 ± 0.25	0.35
		0.82 ± 0.06	0.33 ± 0.08	lost	0.054 ± 0.006	15.2	6.1		0.35
9-17	9-18	0.34 ± 0.04	0.09 ± 0.04	0.36 ± 0.10	0.018 ± 0.004	18.9	5.0	34.12 ± 0.25	0.08
		0.32 ± 0.04	<0.06	lost	0.011 ± 0.003	29.1	< 5.5		0.08
9-18	9-21	1.56 ± 0.10	0.43 ± 0.11	2.97 ± 0.18	0.041 ± 0.004	38.0	10.5	34.16 ± 0.25	1.08
		1.73 ± 0.15	0.51 ± 0.15	2.29 ± 0.20	0.051 ± 0.006	33.9	10.0		1.08
9-21	9-22	0.37 ± 0.04	lost	0.15 ± 0.08	0.020 ± 0.005	18.5	—	34.18 ± 0.25	0.08
		0.37 ± 0.04	lost	0.59 ± 0.08	0.019 ± 0.007	19.5	—		0.08
9-22	9-27	4.81 ± 0.35	2.39 ± 0.51	2.75 ± 0.23	0.164 ± 0.009	29	15	34.34 ± 0.25	1.14
		4.52 ± 0.20	1.18 ± 0.35	5.02 ± 0.28	0.155 ± 0.010	29	8		1.14
9-27	10-1	1.39 ± 0.07	0.36 ± 0.10	1.31 ± 0.12	0.063 ± 0.009	22	6	34.41 ± 0.25	0.33
		1.42 ± 0.12	0.58 ± 0.12	1.24 ± 0.15	0.067 ± 0.007	21	9		0.33
10-1	10-11	0.26 ± 0.06	0.61 ± 0.14	2.83 ± 0.20	0.020 ± 0.004	13	31	34.42 ± 0.25	dry
		0.23 ± 0.03	0.17 ± 0.05	2.38 ± 0.20	0.014 ± 0.002	16	12		dry
10-11	10-18	0.78 ± 0.10	3.47 ± 0.30	1.20 ± 0.12	0.034 ± 0.003	22.9	102.1	34.46 ± 0.25	0.04
		1.30 ± 0.12	3.37 ± 0.20	1.43 ± 0.20	0.033 ± 0.005	39.4	102.1		0.04
10-18	10-23	2.39 ± 0.25	5.6 ± 0.4	1.84 ± 0.25	0.076 ± 0.006	31	74	34.52 ± 0.25	0.08
		1.95 ± 0.12	5.0 ± 0.3	2.49 ± 0.28	0.056 ± 0.012	35	89		0.08

Table 4 - Cont'd.

PRECIPITATION COLLECTIONS - Pittsburgh, Pennsylvania - Cont'd.

Collector Area: 2.58 ft²

Sampling Period from	to	At Midpoint of Sampling Period: mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	mc Sr^{90}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958									
10-23	10-25	2.64 ± 0.12 2.66 ± 0.13	10.3 ± 1.1 7.4 ± 0.4	0.85 ± 0.16 0.79 ± 0.15	0.061 ± 0.006 0.064 ± 0.005	43 42	169 116	34.58 ± 0.25	0.21 0.21
10-25	10-26	2.07 ± 0.10 2.03 ± 0.16	6.6 ± 0.3 7.1 ± 0.4	0.73 ± 0.14 0.54 ± 0.10	0.046 ± 0.005 0.048 ± 0.005	45 42	143 148	34.63 ± 0.25	0.21 0.21
10-26	10-28	3.69 ± 0.16 3.71 ± 0.18	12.2 ± 0.6 13.0 ± 0.8	0.93 ± 0.14 1.13 ± 0.15	0.087 ± 0.006 0.086 ± 0.005	42 43	140 151	34.72 ± 0.25	0.28 0.28
10-28	11-2	0.67 ± 0.07 0.59 ± 0.08	2.39 ± 0.16 lost	0.29 ± 0.09 0.32 ± 0.10	0.020 ± 0.005 0.018 ± 0.003	34 33	120 —	34.74 ± 0.25	0.02 0.02
11-2	11-3	5.02 ± 0.35 5.28 ± 0.35	11.7 ± 0.5 9.8 ± 0.4	1.36 ± 0.14 lost	0.089 ± 0.006 0.079 ± 0.006	56 67	131 124	34.82 ± 0.25	0.31 0.31
11-3	11-6	0.40 ± 0.03 0.46 ± 0.04	0.58 ± 0.04 1.37 ± 0.07	0.31 ± 0.09 0.19 ± 0.09	0.004 ± 0.002 0.005 ± 0.003	100 92	145 274	34.82 ± 0.25	0.02 0.02
11-6	11-9	3.19 ± 0.13 2.88 ± 0.15	2.96 ± 0.15 5.12 ± 0.24	0.82 ± 0.08 0.73 ± 0.13	0.075 ± 0.005 0.071 ± 0.004	43 41	39 72	34.90 ± 0.25	0.13 0.13
11-9	11-10	3.47 ± 0.15 3.37 ± 0.16	4.43 ± 0.22 3.34 ± 0.26	1.00 ± 0.16 0.29 ± 0.15	0.083 ± 0.006 0.066 ± 0.004	42 51	53 51	34.97 ± 0.25	0.30 0.30
11-10	11-15	3.65 ± 0.16 3.38 ± 0.30	8.0 ± 0.4 6.7 ± 0.4	1.65 ± 0.13 1.52 ± 0.14	0.109 ± 0.008 0.097 ± 0.013	33 35	73 69	35.07 ± 0.25	0.25 0.25
11-15	11-16	0.40 ± 0.05 0.36 ± 0.05	2.20 ± 0.20 1.22 ± 0.09	0.74 ± 0.16 0.30 ± 0.09	0.009 ± 0.004 0.017 ± 0.003	44 21	244 72	35.59 ± 0.25	trace trace
11-16	11-17	0.67 ± 0.04 0.60 ± 0.05	1.21 ± 0.16 1.35 ± 0.12	0.34 ± 0.07 0.24 ± 0.08	0.012 ± 0.003 0.014 ± 0.008	56 43	101 96	35.61 ± 0.25	0.03 0.03
11-17	11-18	0.91 ± 0.05 0.86 ± 0.07	1.03 ± 0.06 1.17 ± 0.05	0.34 ± 0.08 0.18 ± 0.09	0.016 ± 0.003 0.023 ± 0.005	57 37	64 51	35.63 ± 0.25	0.04 0.04
11-18	11-19	2.86 ± 0.12 2.72 ± 0.14	1.57 ± 0.07 2.35 ± 0.11	lost 0.36 ± 0.08	0.099 ± 0.004 0.059 ± 0.005	48 46	87 40	35.69 ± 0.25	0.19 0.19
11-19	11-24	1.24 ± 0.06 1.14 ± 0.08	1.57 ± 0.07 1.51 ± 0.12	1.01 ± 0.25 0.87 ± 0.10	0.043 ± 0.005 0.046 ± 0.018	29 25	37 33	35.73 ± 0.25	0.02 0.02
11-24	11-26	0.82 ± 0.04 0.79 ± 0.04	0.94 ± 0.06 0.86 ± 0.06	0.42 ± 0.15 0.54 ± 0.25	0.026 ± 0.006 0.033 ± 0.006	32 24	36 26	35.76 ± 0.25	0.02 0.02
11-26	11-29	3.45 ± 0.15 3.04 ± 0.16	1.99 ± 0.12 2.72 ± 0.13	0.59 ± 0.18 2.48 ± 0.25	0.080 ± 0.006 0.073 ± 0.006	43 42	25 37	35.83 ± 0.25	0.98 0.98

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Table 4 - Cont'd.

PRECIPITATION COLLECTIONS - Pittsburgh, Pennsylvania - Cont'd.

Collector Area: 2.58 ft^2

Sampling from	Period to	At Midpoint of Sampling Period: mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	mc Sr^{90}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958									
11-29	12-4	2.75 ± 0.13	1.93 ± 0.18	1.45 ± 0.13	0.074 ± 0.009	37	26	35.92 ± 0.25	0.26
		4.07 ± 0.20	2.53 ± 0.11	1.89 ± 0.14	0.130 ± 0.016	31	19		0.26
12-4	12-6	5.10 ± 0.05	2.95 ± 0.14	2.78 ± 0.21	0.141 ± 0.007	36	21	36.00 ± 0.25	0.39
		2.11 ± 0.22	1.27 ± 0.09	1.09 ± 0.14	0.069 ± 0.005	31	18		0.39
12-6	12-9	2.76 ± 0.18	2.12 ± 0.40	1.28 ± 0.12	0.081 ± 0.005	34	26	36.10 ± 0.25	0.13
		4.96 ± 0.35	3.23 ± 0.45	2.14 ± 0.16	0.118 ± 0.013	42	27		0.13
12-9	12-14	1.01 ± 0.06	0.56 ± 0.08	1.51 ± 0.12	0.044 ± 0.008	23	13	36.15 ± 0.25	0.06
		0.92 ± 0.06	0.45 ± 0.06	1.41 ± 0.13	0.053 ± 0.006	17	8		0.06
12-14	12-17	0.93 ± 0.15	0.48 ± 0.04	1.56 ± 0.12	0.029 ± 0.004	32	17	36.18 ± 0.25	trace
		0.74 ± 0.05	0.47 ± 0.06	1.23 ± 0.13	0.031 ± 0.004	24	15		trace
12-17	12-20	3.88 ± 0.17	1.31 ± 0.09	1.86 ± 0.12	0.091 ± 0.011	43	14	36.28 ± 0.25	0.21
		3.77 ± 0.18	1.06 ± 0.09	1.85 ± 0.12	0.108 ± 0.010	35	10		0.21
12-20	12-23	3.57 ± 0.18	0.75 ± 0.08	0.97 ± 0.09	0.082 ± 0.007	44	9	36.37 ± 0.25	0.11
		2.89 ± 0.13	0.65 ± 0.06	1.29 ± 0.11	0.097 ± 0.004	30	7		0.11
12-23	12-31	0.74 ± 0.07	0.18 ± 0.04	1.15 ± 0.11	0.023 ± 0.003	32	8	36.39 ± 0.25	dry
		0.73 ± 0.05	0.11 ± 0.04	1.15 ± 0.11	0.022 ± 0.004	33	5		dry

Table 5

PRECIPITATION COLLECTIONS - Westwood, New Jersey

Sampling Period from	to	At Midpoint of Sampling Period: mc Sr^{90}/mi^2	mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	Precipitation in inches
1958								
2-4	2-10	0.013 ± 0.002 0.049 ± 0.002	0.111 ± 0.006 0.442 ± 0.009	0.075 ± 0.060 0.293 ± 0.018	8.5 9.0	5.8 6.0	0.031 ± 0.025	0.754
2-10	2-17	0.015 ± 0.002 0.007 ± 0.002	0.024 ± 0.022 0.009 ± 0.004	≤ 0.011 ≤ 0.011	1.6 1.3		0.042 ± 0.026	0.149
2-17	2-25	0.005 ± 0.002 0.012 ± 0.002	≤ 0.020 0.024 ± 0.004	0.007 0.018 ± 0.003	<4.0 2.0	— 1.5	0.050 ± 0.026	0.000
2-25	2-28	0.256 ± 0.011 0.439 ± 0.006	4.278 ± 0.063 5.58 ± 0.09	0.499 ± 0.025 0.374 ± 0.008	17 13	1.9 0.8	0.398 ± 0.133	0.188
2-28	3-1	0.010 ± 0.027 ≤ 0.002	0.080 ± 0.015 0.099 ± 0.004	0.027 ± 0.003 0.004 ± 0.002	8.0 —	2.7 —	0.404 ± 0.133	0.005
3-1	3-3	0.026 ± 0.003 0.064 ± 0.002	0.275 ± 0.006 0.707 ± 0.010	0.046 ± 0.005 0.055 ± 0.009	10 11	1.8 0.9	0.449 ± 0.136	0.139
3-3	3-4	0.033 ± 0.009	0.522 ± 0.042	0.034 ± 0.008	16	1.0	0.482 ± 0.136	0.600
3-4	3-10	0.010 ± 0.002 ≤ 0.002	0.013 ± 0.009 0.019 ± 0.007	≤ 0.005 ≤ 0.011	1.3 —	— —	0.488 ± 0.136	0.000
3-10	3-15	0.230 ± 0.009 0.285 ± 0.011	2.77 ± 0.05 3.56 ± 0.06	0.846 ± 0.030 4.337 ± 0.062	12 12	3.7 15	0.746 ± 0.141	1.409
3-15	3-20	0.0552 ± 0.005 0.0784 ± 0.0026	0.453 ± 0.018 0.877 ± 0.017	0.537 0.666 ± 0.121	8.2 11	9.7 8.5	0.812 ± 0.142	0.529
3-20	3-21	0.117 ± 0.003 0.085 ± 0.003	1.44 ± 0.03 1.187 ± 0.025	1.18 0.773 ± 0.077	12 14	10 9.1	0.913 ± 0.144	0.559

Table 5 - Cont'd.

PRECIPITATION COLLECTIONS - Westwood, New Jersey

Sampling Period from 1958	to	As Midpoint of Sampling Period: mc Sr^{90}/mi^2	mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	Precipitation in inches
3-21	3-22	0.005 ± 0.002 ≤ 0.0020	0.036 ± 0.007 0.0433 ± 0.0065	0.035 ± 0.007 0.0267 ± 0.0073	7.2 —	3.0 —	0.936 ± 0.144	0.031
3-22	3-25	0.025 ± 0.004 0.021 ± 0.005	0.434 ± 0.01 0.386 ± 0.014	0.260 0.252	17 16	10 18	0.962 ± 0.144	0.020
3-25	3-27	0.113 ± 0.003 0.128 ± 0.003	1.87 ± 0.02 2.17 ± 0.03	- 0.585 1.414 ± 0.198	16 17	— 11	1.062 ± 0.145	0.290
3-27	3-31	0.0708 ± 0.0021 0.0898 ± 0.0026	1.56 ± 0.02 2.09 ± 0.02	1.74 1.71	22 25	24 20	1.140 ± 0.145	0.300
3-31	4-1	0.023 ± 0.003 0.0292 ± 0.0026	0.915 ± 0.014 1.08 ± 0.01	1.79 ± 0.179 1.57	40 37	78 53	1.166 ± 0.145	0.190
4-1	4-7	0.444 ± 0.015 0.481 ± 0.015	13.1 ± 0.1 12.4 ± 0.1	16.5 20.5	30 29	37 43	1.599 ± 0.146	1.949
4-7	4-8	0.011 ± 0.002 0.020 ± 0.002	1.566 ± 0.013 0.831 ± 0.012	2.97 ± 0.30 1.18 ± 0.12	142 41	270 59	1.614 ± 0.146	0.349
4-8	4-14	0.446 ± 0.055 0.212 ± 0.004	11.3 ± 0.1 7.12 ± 0.08	16.0 2.070 ± 0.163	25 34	36 9.8	1.944 ± 0.221	1.329
4-14	4-21	0.069 ± 0.008 0.034 ± 0.003	0.865 ± 0.023 1.101 ± 0.012	1.06 ± 0.11 2.05 ± 0.20	12 32	15 60	1.995 ± 0.222	0.020
4-21	4-22	0.009 ± 0.003 0.032 ± 0.004	0.208 ± 0.010 0.257 ± 0.016	0.445 ± 0.098 0.264 ± 0.019	23 8.0	49 8.2	2.015 ± 0.223	0.010
4-22	4-24	0.168 ± 0.005 0.282 ± 0.007	2.862 ± 0.025 3.021 ± 0.031	1.140 ± 0.015 1.101 ± 0.081	17 11	6.8 3.9	2.240 ± 0.237	0.600
4-24	4-28	0.327 ± 0.008 0.201 ± 0.006	5.705 ± 0.040 4.628 ± 0.031	1.087 2.224 ± 0.088	17 23	11	2.504 ± 0.253	1.439

4-24	4-28	0.327 ± 0.008 0.201 ± 0.006	5.705 ± 0.040 4.628 ± 0.031	LOST 2.224 ± 0.026	17 23	11	2.504 ± 0.253	1.439

Table 5 - Cont'd.

PRECIPITATION COLLECTIONS - Westwood, New Jersey

Sampling From 1958	Period To	At Midpoint of Sampling Period: mc Sr^{90}/mi^2	mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc I^{185}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	Precipitation in Inches
4-28	4-29	0.036 ± 0.004 0.058 ± 0.004	0.324 ± 0.013 0.250 ± 0.018	0.322 ± 0.039 0.162 ± 0.026		9.0 4.3	8.9 2.8	2.552 ± 0.254	0.020
4-29	4-30	0.216 ± 0.006 0.158 ± 0.005	4.642 ± 0.032 3.276 ± 0.025	1.733 ± 0.057 1.325 ± 0.044		21 21	8.0 8.4	2.738 ± 0.257	1.129
4-30	5-5	0.308 ± 0.006 0.272 ± 0.010	4.518 ± 0.031 4.371 ± 0.034	2.397 ± 0.046 2.385 ± 0.042		15 16	7.8 8.8	3.028 ± 0.258	0.900
5-5	5-6	0.045 ± 0.017 0.296 ± 0.049	0.685 ± 0.051 4.397 ± 0.033	1.313 ± 0.023 1.707 ± 0.005		15 15	29 5.7	3.199 ± 0.313	0.439
5-6	5-8	0.281 ± 0.005 0.174 ± 0.005	4.816 ± 0.104 3.226 ± 0.031	1.424 ± 0.062 1.299 ± 0.018		17 18	5.1 7.4	3.426 ± 0.320	0.949
5-8	5-12	0.200 ± 0.011 0.279 ± 0.006	2.987 ± 0.089 5.516 ± 0.056	0.624 ± 0.018 1.981 ± 0.020	≤0.015 ≤0.037	15 20	3.1 7.1	3.666 ± 0.327	0.500
5-12	5-16	0.612 ± 0.008 0.564 ± 0.007	9.720 ± 0.051 6.189 ± 0.057	2.304 ± 0.028 1.551 ± 0.019	≤0.011 ≤0.033	16 11	3.8 2.8	4.254 ± 0.329	0.320
5-16	5-19	0.070 ± 0.004 0.073 ± 0.004	0.808 ± 0.016 0.676 ± 0.017	0.188 ± 0.010 0.229 ± 0.011	≤0.031 ≤0.053	12 9.3	2.7 3.1	4.326 ± 0.329	0.059
5-19	5-20	0.100 ± 0.004 0.079 ± 0.004	1.472 ± 0.018 1.333 ± 0.017	0.456 ± 0.015 0.421 ± 0.013	0.41 ± 0.02 0.13 ± 0.02	15 17	4.6 5.3	4.415 ± 0.329	0.149
5-20	5-21	0.127 ± 0.005 0.119 ± 0.004	1.310 ± 0.015 1.141 ± 0.014	0.344 ± 0.012 0.251 ± 0.010	≤0.070 ≤0.049	10 9.6	2.7 2.1	4.538 ± 0.329	0.030
5-21	5-23	0.142 ± 0.009 0.127 ± 0.010	1.354 ± 0.074 1.823 ± 0.060	0.348 ± 0.018 0.260 ± 0.017	≤0.043 ≤0.032	9.5 14	2.4 2.0	4.672 ± 0.329	0.059

Table 5 - Cont'd.

PRECIPITATION COLLECTIONS - Westwood, New Jersey

Sampling Period from 1958	to	At Midpoint of Sampling Period: mc Sr^{90}/mi^2	mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	Precipitation in inches
5-23	5-26	0.729 ± 0.012	1.946 ± 0.029	1.494 ± 0.040	0.80 ± 0.02	2.7	2.0	5.378 ± 0.331	0.900
		0.682 ± 0.011	2.107 ± 0.026	1.629 ± 0.021	0.47 ± 0.02	3.1	2.4		
5-26	5-29	0.079 ± 0.008	0.228 ± 0.008	0.239 ± 0.013	0.20 ± 0.02	2.9	3.0	5.464 ± 0.331	0.049
		0.092 ± 0.008	0.268 ± 0.007	0.319 ± 0.012	0.18 ± 0.01	2.9	3.5		
5-29	6-3	0.024 ± 0.004	0.131 ± 0.006	0.310 ± 0.026	0.23 ± 0.03	5.4	13	5.488 ± 0.331	0.010
		0.025 ± 0.006	0.128 ± 0.007	0.292 ± 0.022	0.22 ± 0.03	5.1	12		
6-3	6-10	0.168 ± 0.014	2.305 ± 0.109	3.607 ± 0.105	1.25 ± 0.05	14	21	5.710 ± 0.340	0.12
		0.277 ± 0.014	2.213 ± 0.115	2.848 ± 0.082	1.09 ± 0.03	8.0	10		
6-10	6-11	0.133 ± 0.012	3.01 ± 0.07	1.663 ± 0.033	1.32 ± 0.03	23	12	5.839 ± 0.340	0.19
		0.124 ± 0.023	2.752 ± 0.176	1.841 ± 0.031	1.39 ± 0.07	22	15		
6-11	6-12	0.040 ± 0.006	1.059 ± 0.052	0.705 ± 0.021	0.62 ± 0.03	26	18	5.893 ± 0.340	0.045
		0.068 ± 0.005	1.122 ± 0.044	0.785 ± 0.029	0.54 ± 0.02	16	12		
6-12	6-14	0.143 ± 0.003	2.902 ± 0.046	2.71 ± 0.27	1.19 ± 0.04	20	19	6.034 ± 0.340	0.45
		0.138 ± 0.014	3.129 ± 0.083	2.27 ± 0.23	1.12 ± 0.03	23	16		
6-14	6-19	0.181 ± 0.015	0.890 ± 0.09	0.461 ± 0.046	0.30 ± 0.02	4.9	2.5	6.256 ± 0.345	0.68
		0.263 ± 0.013	1.53 ± 0.08	0.481 ± 0.04	0.32 ± 0.02	5.8	1.8		
6-19	6-23	0.151 ± 0.003	2.075 ± 0.038	0.582 ± 0.013	0.18 ± 0.01	14	3.8	6.428 ± 0.347	0.72
		0.194 ± 0.003	2.114 ± 0.042	0.560 ± 0.018	0.60 ± 0.02	11	2.9		
6-23	6-27	0.103 ± 0.005	2.486 ± 0.046	2.155 ± 0.036	0.27 ± 0.01	24	21	6.538 ± 0.347	0.50
		0.118 ± 0.003	2.440 ± 0.041	2.780 ± 0.056	0.38 ± 0.01	21	24		
6-27	7-3	0.021 ± 0.002 ±0.009	0.489 ± 0.030	0.851 ± 0.019	0.34 ± 0.01	23	40	6.552 ± 0.347	0.00
			0.356 ± 0.024	0.635 ± 0.014	0.27 ± 0.02				
7-3	7-7	0.211 ± 0.004	6.550 ± 0.055	11.716 ± 0.056	0.94 ± 0.01	31	56	6.727 ± 0.351	0.92
		0.138 ± 0.009	4.929 ± 0.047	8.430 ± 0.050	0.68 ± 0.01	36	61		

Table 5 - Cont'd.

Table 5 - Cont'd.

PRECIPITATION COLLECTIONS - Westwood, New Jersey

Sampling Period from	to	At Midpoint of Sampling Period: mc Sr^{90}/mi^2	mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	Precipitation in inches
1958									
7-7	7-9	0.074 ± 0.009	2.865 ± 0.045	7.528 ± 0.041	1.85 ± 0.02	39	102	6.784 ± 0.351	0.58
		0.041 ± 0.009	2.275 ± 0.039	6.873 ± 0.036	1.87 ± 0.02	55	168		
7-9	7-14	0.135 ± 0.005	6.290 ± 0.054	10.997 ± 0.111	2.13 ± 0.02	46	81	6.924 ± 0.352	0.23
		0.145 ± 0.012	4.923 ± 0.070	12.245 ± 0.163	1.75 ± 0.02	34	84		
7-14	7-16	0.121 ± 0.010	4.873 ± 0.049	7.225 ± 0.068	2.39 ± 0.02	40	60	7.025 ± 0.352	0.23
		0.060 ± 0.004	4.671 ± 0.043	6.654 ± 0.061	2.01 ± 0.01	58	83		
7-16	7-17	0.035 ± 0.003	1.21 ± 0.02	2.05 ± 0.10	0.83 ± 0.03	34	58	7.054 ± 0.353	0.15
		0.024 ± 0.002	1.23 ± 0.01	1.70 ± 0.08	0.88 ± 0.01	51	71		
7-17	7-23	0.042 ± 0.003	2.19 ± 0.02	3.99 ± 0.17	2.95 ± 0.03	52	95	7.102 ± 0.353	0.09
		0.053 ± 0.004	2.05 ± 0.03	3.56 ± 0.15	2.39 ± 0.02	38	67		
7-23	7-29	0.192 ± 0.004	11.1 ± 0.08	16.86 ± 0.72	5.32 ± 0.23	58	88	7.308 ± 0.355	0.82
		0.218 ± 0.004	11.3 ± 0.08	17.25 ± 0.73	7.04 ± 0.04	52	79		
7-29	8-1	0.038 ± 0.002	1.40 ± 0.03	2.24 ± 0.10	2.60 ± 0.02	37	59	7.342 ± 0.355	0.17
		0.032 ± 0.002	1.24 ± 0.03	1.55 ± 0.07	2.33 ± 0.02	38	48		
8-1	8-8	0.015 ± 0.003	0.162 ± 0.030	0.502 ± 0.036	Lost	11	33	7.354 ± 0.353	0.00
		≤0.009	0.157 ± 0.024	0.406 ± 0.067	Lost				
8-8	8-11	0.281 ± 0.005	5.80 ± 0.03	3.13 ± 0.13	2.47 ± 0.05	21	11	7.618 ± 0.354	1.08
		0.246 ± 0.006	5.21 ± 0.03	2.83 ± 0.12	2.04 ± 0.03	21	12		
8-11	8-13	0.072 ± 0.003	3.24 ± 0.03	2.68 ± 0.11	2.61 ± 0.05	45	37	7.692 ± 0.354	0.22
		0.077 ± 0.009	3.34 ± 0.06	2.54 ± 0.15	2.75 ± 0.03	43	30		
8-13	8-15	0.051 ± 0.002	1.91 ± 0.02	1.44 ± 0.06	2.63 ± 0.04	37	28	7.742 ± 0.354	0.045
		0.050 ± 0.003	1.94 ± 0.02	1.36 ± 0.06	2.71 ± 0.04	39	27		

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Table 5 - Cont'd.

PRECIPITATION COLLECTIONS - Westwood, New Jersey

Sampling Period from	to	At Midpoint of Sampling Period: mc Sr^{90}/mi^2	mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958									
8-15	8-18	0.269 ± 0.007	7.08 ± 0.29	3.42 ± 0.15	5.35 ± 0.01	28.4	13.7	8.00 ± 0.35	0.76
		0.268 ± 0.007	7.60 ± 0.31	3.39 ± 0.14	3.96 ± 0.05	28.4	12.6		0.76
8-18	8-23	0.058 ± 0.003	1.37 ± 0.06	0.93 ± 0.04	lost	23.6	16.0	8.06 ± 0.35	0.05
		0.064 ± 0.003	1.81 ± 0.07	1.06 ± 0.05	lost	28.3	16.6		0.05
8-23	8-25	0.114 ± 0.004	4.22 ± 0.17	2.32 ± 0.10	6.12 ± 0.01	37.0	20.4	8.18 ± 0.36	1.38
		0.122 ± 0.004	4.52 ± 0.18	2.34 ± 0.10	5.76 ± 0.01	37.0	19.2		1.38
8-25	9-4	0.015 ± 0.004	0.20 ± 0.02	0.30 ± 0.03	3.13 ± 0.04	13.6	20.2	8.20 ± 0.36	--
		0.022 ± 0.004	0.17 ± 0.02	0.32 ± 0.02	3.48 ± 0.04	7.9	14.5		--
9-4	9-8	0.101 ± 0.004	2.96 ± 0.12	0.93 ± 0.04	5.07 ± 0.08	29.3	9.2	8.30 ± 0.36	0.69
		0.099 ± 0.004	2.59 ± 0.10	0.94 ± 0.04	5.68 ± 0.06	26.2	9.5		0.69
9-8	9-10	0.018 ± 0.003	0.46 ± 0.03	0.26 ± 0.03	lost	25.8	14.3	8.31 ± 0.36	0.03
		0.014 ± 0.002	0.51 ± 0.03	0.28 ± 0.03	2.33 ± 0.04	36.2	19.5		0.03
9-10	9-18	0.133 ± 0.007	4.51 ± 0.18	1.38 ± 0.06	9.06 ± 0.10	33.9	10.4	8.45 ± 0.36	1.72
		0.139 ± 0.006	4.26 ± 0.17	1.38 ± 0.09	11.2 ± 0.1	30.6	9.9		1.72
9-18	9-22	0.083 ± 0.006	1.99 ± 0.08	0.44 ± 0.02	5.56 ± 0.07	24.0	5.3	8.53 ± 0.36	0.64
		0.076 ± 0.004	1.86 ± 0.07	0.85 ± 0.05	4.67 ± 0.06	24.4	11.1		0.64
9-22	9-27	0.133 ± 0.005	3.58 ± 0.14	0.84 ± 0.004	lost	26.9	6.3	8.66 ± 0.36	0.64
		0.125 ± 0.004	3.44 ± 0.13	1.55 ± 0.05	lost	27.9	12.6		0.64
9-27	9-30	0.057 ± 0.003	1.65 ± 0.02	0.21 ± 0.01	lost	29.2	3.6	8.71 ± 0.36	0.14
		----	Lost due to defect in collection pot		----				0.14
9-30	10-2	0.140 ± 0.004	3.13 ± 0.14	5.42 ± 0.15	6.06 ± 0.08	22.3	38.7	8.85 ± 0.36	1.03
		0.139 ± 0.005	3.30 ± 0.14	1.44 ± 0.06	5.97 ± 0.08	23.7	10.3		1.03
10-2	10-10	0.029 ± 0.005	0.27 ± 0.03	1.47 ± 0.14	1.67 ± 0.01	9.1	50.3	8.90 ± 0.36	0.02
		0.055 ± 0.008	0.31 ± 0.04	2.17 ± 0.11	2.22 ± 0.02	5.6	39.2		0.02
10-10	10-14	0.027 ± 0.007	0.60 ± 0.02	1.58 ± 0.04	1.53 ± 0.02	22.0	57.8	8.93 ± 0.36	0.04
		0.044 ± 0.004	0.79 ± 0.02	2.56 ± 0.12	1.21 ± 0.02	17.7	57.9		0.04
10-14	10-15	----	Lost due to defect in collection pot		----			8.98 ± 0.36	0.09
		0.043 ± 0.003	2.19 ± 0.02	6.69 ± 0.10	lost	51.4	157.0		0.09
10-15	10-22	0.023 ± 0.003	0.35 ± 0.01	2.98 ± 0.15	lost	15.3	129.5	9.00 ± 0.36	dry
		0.020 ± 0.003	0.40 ± 0.03	2.79 ± 0.09	lost	19.7	139.5		dry

Table 5 - Cont'd.

PRECIPITATION COLLECTIONS - Westwood, New Jersey

Sampling Period from	to	At Midpoint of Sampling Period: mc Sr^{90}/mi²	mc Sr^{89}/mi²	mc Ba^{140}/mi²	mc Y^{185}/mi²	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi²	ppt'n. in inches
1958									
10-22	10-23	0.121 ± 0.005	3.57 ± 0.32	4.09 ± 0.07	lost	29.5	33.8	9.14 ± 0.36	1.59
		0.173 ± 0.005	5.21 ± 0.02	4.92 ± 0.02	6.52 ± 0.04	30.1	28.4		1.59
10-23	10-27	----	Lost due to defect in collection pot		-----			9.76 ± 0.36	2.40
		0.616 ± 0.006	36.4 ± 0.5	156 ± 1	13.9 ± 0.1	59.0	253.2		2.40
10-27	10-29	0.067 ± 0.004	3.95 ± 0.05	17.3 ± 0.5	1.26 ± 0.02	58.9	258.2	9.83 ± 0.36	0.09
		0.077 ± 0.004	3.56 ± 0.04	13.3 ± 0.2	1.38 ± 0.01	46.2	172.8		0.09
10-29	11-3	0.275 ± 0.006	12.6 ± 0.1	32.3 ± 0.3	5.73 ± 0.02	45.8	117.0	10.10 ± 0.36	0.72
		0.267 ± 0.006	12.2 ± 0.1	27.9 ± 0.1	8.29 ± 0.05	45.6	104.4		0.72
11-3	11-10	0.245 ± 0.005	8.40 ± 0.07	22.9 ± 0.3	5.61 ± 0.04	34.2	93.4	10.12 ± 0.36	0.32
		0.233 ± 0.004	8.33 ± 0.07	18.6 ± 0.2	6.75 ± 0.04	35.7	79.8		0.32
11-10	11-18	0.453 ± 0.014	16.4 ± 0.1	40.5 ± 0.4	6.68 ± 0.05	36.2	89.4	10.24 ± 0.36	0.70
		0.333 ± 0.008	16.8 ± 0.1	38.0 ± 0.3	8.01 ± 0.04	50.4	114.1		0.70
11-18	11-19	0.021 ± 0.003	0.66 ± 0.02	1.43 ± 0.03	0.99 ± 0.01	31.5	68.7	10.26 ± 0.36	0.09
		0.025 ± 0.003	0.80 ± 0.02	1.53 ± 0.03	0.70 ± 0.003	31.7	60.7		0.09
11-19	11-26	0.131 ± 0.004	4.16 ± 0.05	6.54 ± 0.10	3.00 ± 0.02	32	50	10.39 ± 0.37	0.12
		0.127 ± 0.003	4.28 ± 0.05	5.65 ± 0.11	3.08 ± 0.03	34	44		0.12
11-26	12-1	0.564 ± 0.006	18.5 ± 0.1	19.1 ± 0.1	16.9 ± 0.10	33	34	10.93 ± 0.37	2.30
		0.520 ± 0.006	20.1 ± 0.01	20.7 ± 0.2	17.1 ± 0.10	39	40		
12-1	12-4	0.145 ± 0.004	5.25 ± 0.05	4.95 ± 0.08	3.27 ± 0.03	36	34	11.08 ± 0.37	0.68
		0.162 ± 0.004	5.36 ± 0.04	4.59 ± 0.08	3.83 ± 0.03	33	28		0.68
12-4	12-8	0.087 ± 0.003	3.17 ± 0.03	3.35 ± 0.11	2.39 ± 0.02	37	39	11.17 ± 0.37	0.16
		0.096 ± 0.003	3.11 ± 0.03	2.23 ± 0.09	1.84 ± 0.04	32	23		0.16
12-8	12-10	0.266 ± 0.007	2.91 ± 0.04	2.78 ± 0.05	1.84 ± 0.02	11	12	11.26 ± 0.37	0.20
		0.095 ± 0.003	3.20 ± 0.04	2.63 ± 0.10	1.71 ± 0.02	34	28		0.20
12-10	12-15	0.027 ± 0.003	1.11 ± 0.02	1.39 ± 0.13	1.38 ± 0.03	41	52	11.29 ± 0.37	0.02
		0.043 ± 0.004	1.16 ± 0.03	1.09 ± 0.10	1.10 ± 0.03	27	25		0.02
12-15	12-23	≤0.0042	0.31 ± 0.01	0.43 ± 0.04	0.46 ± 0.26	173	≥122	11.29 ± 0.37	dry
		≤0.0045	0.29 ± 0.02	0.60 ± 0.08	0.26 ± 0.01	165	≥133		dry
12-23	12-30	0.110 ± 0.004	3.50 ± 0.03	1.47 ± 0.04	1.00 ± 0.01	32	13	11.40 ± 0.37	0.22
		0.105 ± 0.004	3.59 ± 0.03	1.27 ± 0.03	0.84 ± 0.01	34	12		0.22

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Table 6

PRECIPITATION COLLECTIONS - Richmond, California

Sampling Period from	to	At Midpoint of Sampling Period: mc Sr^{90}/mi^2	mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958								
3-20	3-21	1.328 ± 0.094	8.72 ± 0.28	61.05 ± 0.45	11	76	1.597 ± 0.265	1.16
		0.270 ± 0.006	12.88 ± 0.15	75.05 ± 0.65	16	94		1.16
3-21	3-24	0.441 ± 0.010	6.84 ± 0.12	67.25 ± 0.75	16	152	2.453 ± 0.268	2.45
		0.416 ± 0.008	9.51 ± 0.16	102.05 ± 1.0	23	245		2.45
3-24	3-26	0.044 ± 0.002	0.989 ± 0.018	3.24 ± 0.06	21	74	2.544 ± 0.271	0.06
		0.047 ± 0.003	0.983 ± 0.037	3.66 ± 0.14	21	78		0.06
3-26	3-28	0.104 ± 0.005	1.51 ± 0.03	5.97 ± 0.10	14	57	2.824 ± 0.289	0.40
		0.176 ± 0.006	1.51 ± 0.03	7.42 ± 0.13	8.5	42		0.40
3-28	4-1	0.460 ± 0.007	12.56 ± 2.03	35.4 ± 0.25	27	77	3.842 ± 0.311	2.58
		0.559 ± 0.012	14.36 ± 2.36	38.7 ± 0.60	26	69		2.58
4-1	4-4	1.012 ± 0.018	7.12 ± 0.13	32.4 ± 0.4	7.0	32	4.798 ± 0.331	1.84
		0.900 ± 0.016	16.77 ± 0.20	29.97 ± 0.33	19	33		1.84
4-4	4-7	0.386 ± 0.008	4.71 ± 0.08	10.30 ± 0.16	12	26	5.166 ± 0.332	0.73
		0.351 ± 0.007	5.16 ± 0.09	14.22 ± 0.22	15	40		0.73
4-7	4-14	0.0070 ± 0.0005	0.088 ± 0.003	0.38 ± 0.02	12	54	5.173 ± 0.332	dry
		0.0078 ± 0.0006	0.117 ± 0.004	0.84 ± 0.03	15	106		dry
4-14	4-21	0.0027 ± 0.0002	0.043 ± 0.002	0.20 ± 0.01	16	74	5.176 ± 0.332	dry
		0.0038 ± 0.0003	0.042 ± 0.002	0.17 ± 0.01	11	45		dry
4-21	4-28	0.0035 ± 0.0004	0.041 ± 0.002	0.12 ± 0.01	12	34	5.180 ± 0.332	dry
		0.0042 ± 0.003	0.047 ± 0.002	0.27 ± 0.01	11	64		dry
4-28	5-5	0.0051 ± 0.0002	0.053 ± 0.002	0.094 ± 0.003	10	18	5.185 ± 0.332	dry
		0.0038 ± 0.0002	0.039 ± 0.002	0.070 ± 0.002	10	18		dry

4-28	5-5	0.0051 ± 0.0002 0.0038 ± 0.0002	0.053 ± 0.002 0.039 ± 0.002	0.094 ± 0.003 0.070 ± 0.002	10 10	18 18	5.185 ± 0.332	dry dry

Table 6 - Cont'd.

PRECIPITATION COLLECTIONS - Richmond, California - Cont'd.

Sampling Period		At Midpoint of Sampling Period							
from	to	mc Sr^{90}/mi^2	mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958									
5-5	5-12	0.062 ± 0.002 0.065 ± 0.002	0.72 ± 0.02 0.69 ± 0.02	0.26 ± 0.01 0.27 ± 0.01	0.037 ± 0.007 0.039 ± 0.002	11.6 10.6	4.3 4.2	5.249 ± 0.332	dry dry
5-12	5-19	0.005 ± 0.0002 0.005 ± 0.0002	0.11 ± 0.01 0.11 ± 0.01	0.60 ± 0.02 0.65 ± 0.02	lost lost	20.4 20.4	111.1 120.4	5.190 ± 0.332	dry dry
5-19	5-24	0.266 ± 0.005 0.353 ± 0.010	6.7 ± 0.1 6.1 ± 0.2	6.1 ± 0.3 7.6 ± 0.2	2.43 ± 0.08 2.30 ± 0.05	25.2 17.3	22.9 21.5	5.559 ± 0.337	dry dry
5-24	6-2	0.020 ± 0.001 0.014 ± 0.001	0.082 ± 0.002 0.081 ± 0.002	0.066 ± 0.004 0.076 ± 0.004	0.141 ± 0.002 0.184 ± 0.002	4.1 5.8	3.3 5.4	5.576 ± 0.337	0.80 0.80
6-2	6-9	0.092 ± 0.002 0.095 ± 0.002	1.04 ± 0.02 1.12 ± 0.02	0.29 ± 0.01 0.31 ± 0.01	lost lost	11.3 11.8	3.2 3.3	5.670 ± 0.337	0.43 0.43
6-9	6-13	0.039 ± 0.001 0.072 ± 0.002	0.373 ± 0.002 0.355 ± 0.005	0.21 ± 0.01 0.18 ± 0.01	2.20 ± 0.02 0.83 ± 0.01	12.9 4.9	5.3 2.5	5.726 ± 0.338	0.04 0.04
6-13	6-20	0.010 ± 0.001 0.014 ± 0.001	0.143 ± 0.002 0.166 ± 0.002	0.100 ± 0.005 0.110 ± 0.005	0.043 ± 0.007 4.9 ± 0.04	14.3 11.9	10.0 7.9	5.738 ± 0.338	dry dry
6-20	6-24	0.010 ± 0.001 0.010 ± 0.001	0.097 ± 0.002 0.128 ± 0.002	0.156 ± 0.005 lost	0.092 ± 0.008 lost	9.7 12.8	15.6 --	5.748 ± 0.338	dry dry
6-24	6-27								
6-27	7-3	0.009 ± 0.001 0.005 ± 0.001	0.039 ± 0.001 0.045 ± 0.001	0.052 ± 0.002 0.073 ± 0.002	0.136 ± 0.006 0.203 ± 0.009	4.3 9.2	5.3 13.9	5.75 ± 0.34	dry dry
7-3	7-11	0.0136 ± 0.0005 0.0141 ± 0.0005	0.274 ± 0.002 0.396 ± 0.008	0.95 ± 0.02 1.64 ± 0.02		20.1 28.0	69.8 116.3	5.77 ± 0.34	dry dry
7-11	7-18	0.019 ± 0.001 lost	0.243 ± 0.008 lost	0.228 ± 0.005 lost		12.7 --	12.0 --	5.79 ± 0.34	dry dry

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Table 7

1958 U. S. SOIL ANALYSES

Sampled by HASL personnel and sent directly to Beltsville for preperation. Aliquots were sent to HASL as blind duplicates. Seventeen locations were sampled and at six locations two sites were sampled.

Site	mc Sr^{90} / mi^2	rate / inch of rain *
Binghamton	42	0.19
Des Moines	84	0.35
Rapid City	74	0.77
Jacksonville	36	0.12
Atlanta	37	0.14
Memphis	37	0.11
Los Angeles	16	0.25
Grand Junction	39	0.75

* Precipitation values used were mean of 1953-58.

Note:- Results for remaining fifteen sites will be available about May 1, and blind duplicates for all sites one week later.

Table 8

REPRODUCIBILITY OF SOIL ANALYSES

Blind Duplicates - 1958 U. S. Soils

Beltsville #	d/m Sr^{90} / kg Soil
592	63 ± 2
5961	65 ± 5
598	52 ± 3
5947	56 ± 3
5919	549 ± 7
5950	574 ± 8
5921	491 ± 8
5978	494 ± 8
5922	38 ± 2
5953	40 ± 2
5924	58 ± 3
5944	53 ± 3
5925	697 ± 25
5960	681 ± 8
5926	46 ± 3
5967	47 ± 3
5931	295 ± 5
5964	282 ± 6
5932	26 ± 3
5972	21 ± 3
5933	181 ± 5
5943	162 ± 6
5936	57 ± 3
5968	49 ± 3
5937	471 ± 7
5966	434 ± 6

Error term - one standard deviation due to counting.

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Table 8 (Contd.)

Blind Duplicates - 1958 U. S. Soils (Contd.)

Beltsville #	d/m/ Sr^{90} / kg Soil
5938	35 ± 3
5981	38 ± 2
5941	480 ± 8
5971	477 ± 17

Blind Duplicates - 1958 Foreign Soils

56453	16 ± 3	
58306	15 ± 3	*
	18 ± 3	
58308	236 ± 7	*
	247 ± 8	
58816	231 ± 6	*
	237 ± 6	
58220	75 ± 5	*
	75 ± 5	
581042	73 ± 3	

* duplicate analyses.

Error term - one standard deviation due to counting.

Table 9

MEAN mc/mi^2 AS OF JUNE 1, 1958

Latitude Band	Aug	Sept	Oct	Nov	Dec
30° - 50° N	73	65	33	61	74
10° - 30° N	-	64	43	40	68
10°N - 10°S	19	9	15	14	-
10° - 30° S	8	26	38	65	34
30° - 50° S	16	10	21	16	20

Table 10

MEAN RATIO AS OF JUNE 1, 1958

Latitude Band	Aug	Sept	Oct	Nov	Dec
30° - 50° N	68	125	58	98	70
10° - 30° N	-	145	72	95	44
10°N - 10°S	119	150	88	117	-
10° - 30° S	73	49	70	162	68
30° - 50° S	50	40	60	80	-

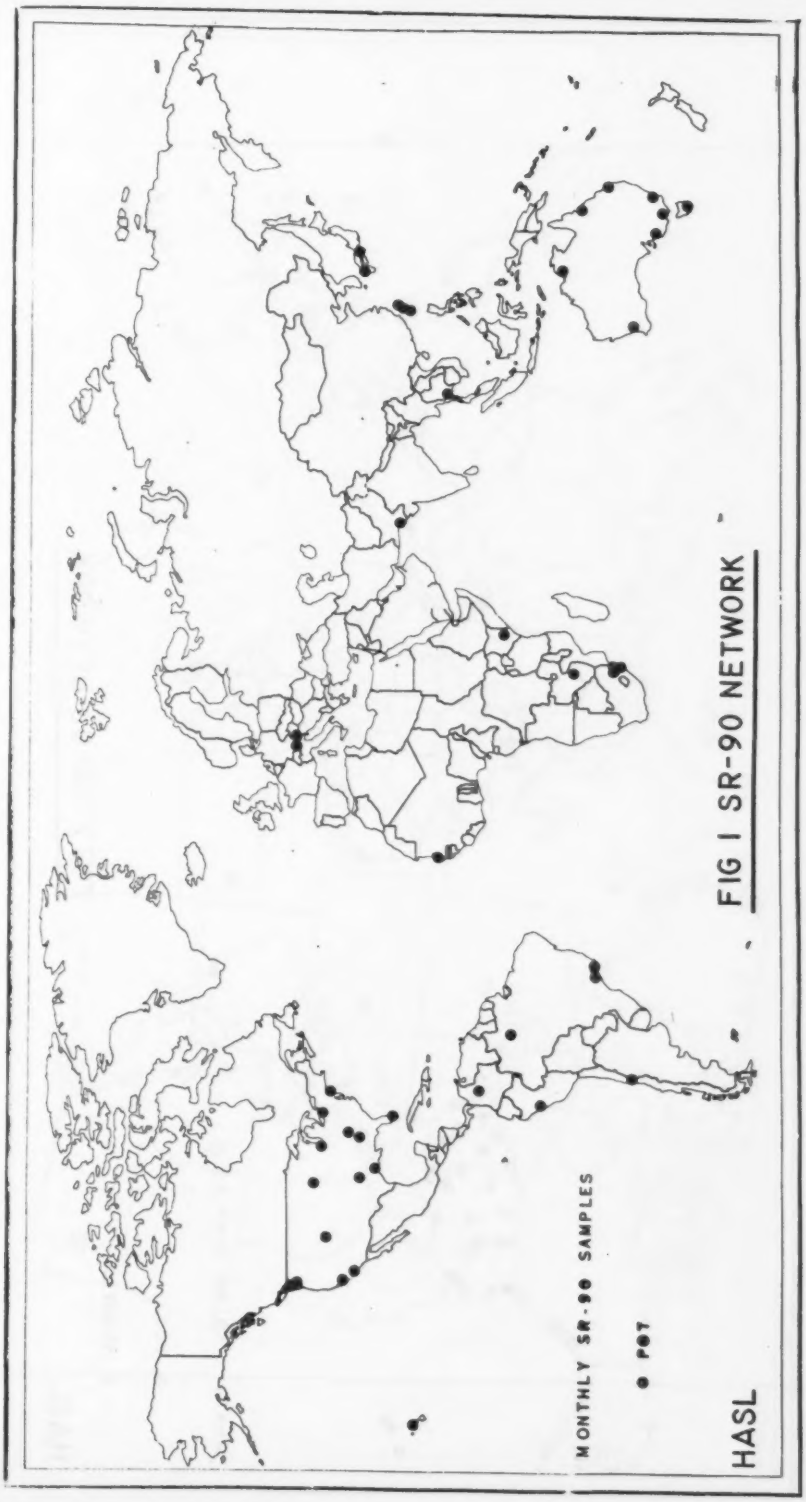


FIG I SR-90 NETWORK

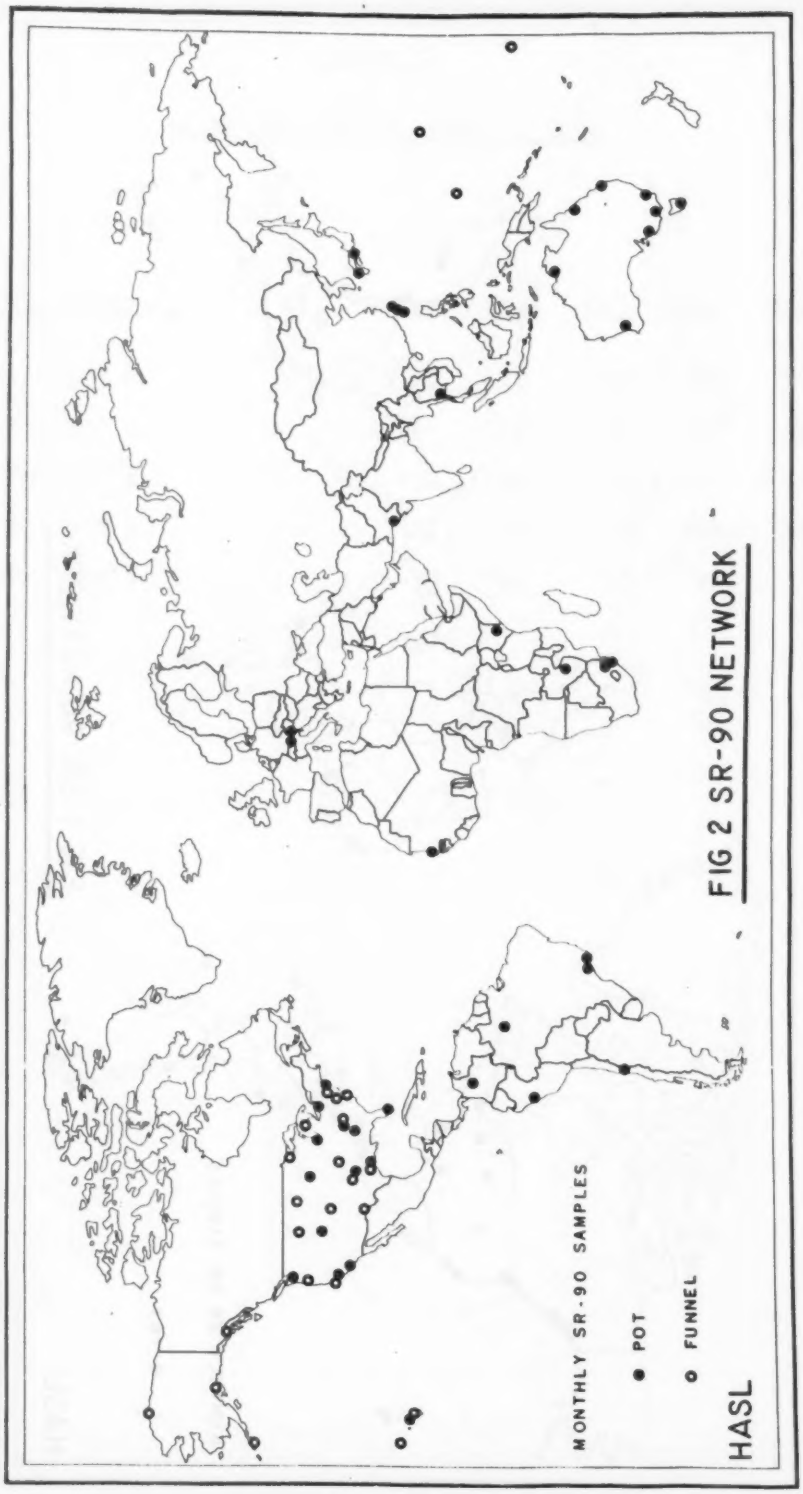


FIG 2 SR-90 NETWORK

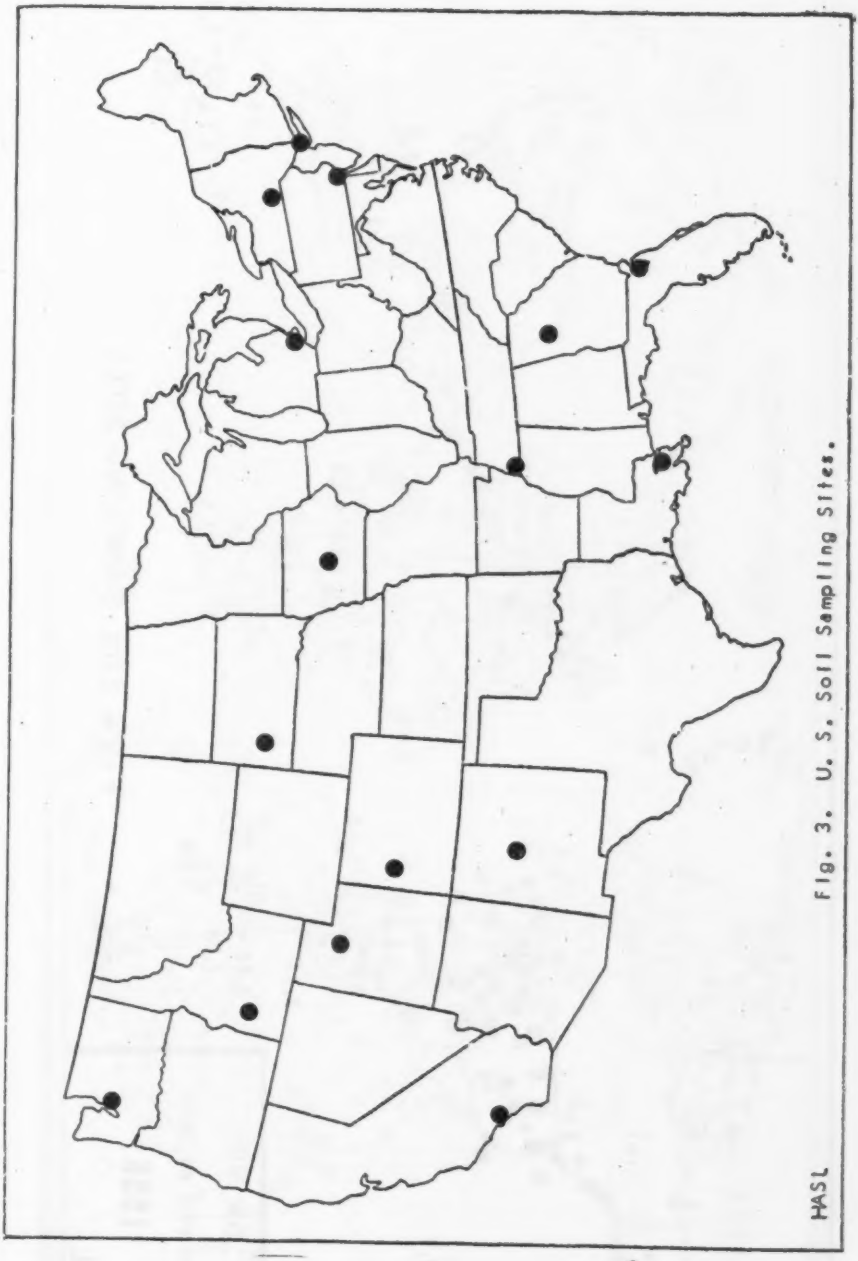


Fig. 3. U. S. Soil Sampling Sites.

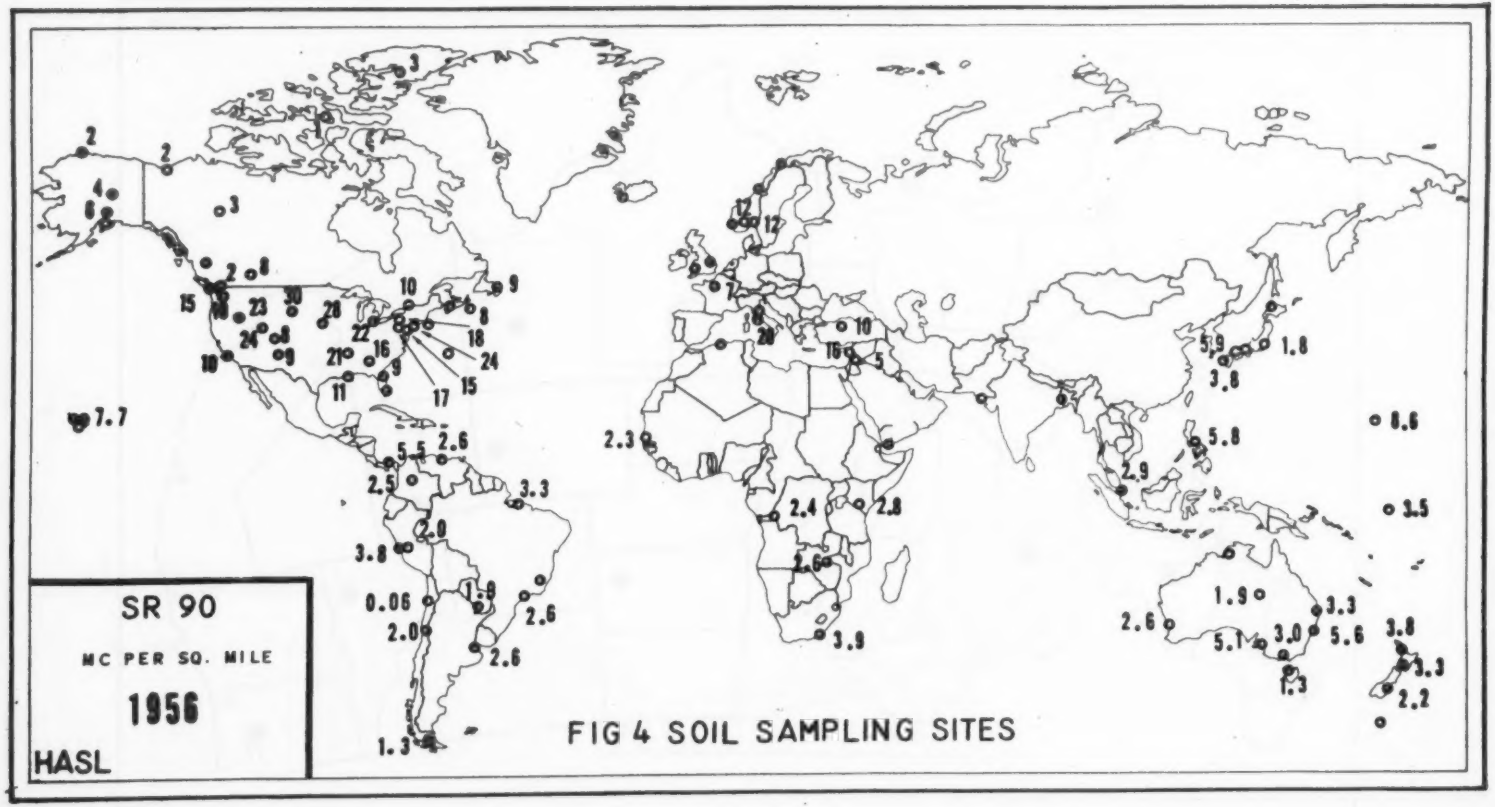


FIG 4 SOIL SAMPLING SITES

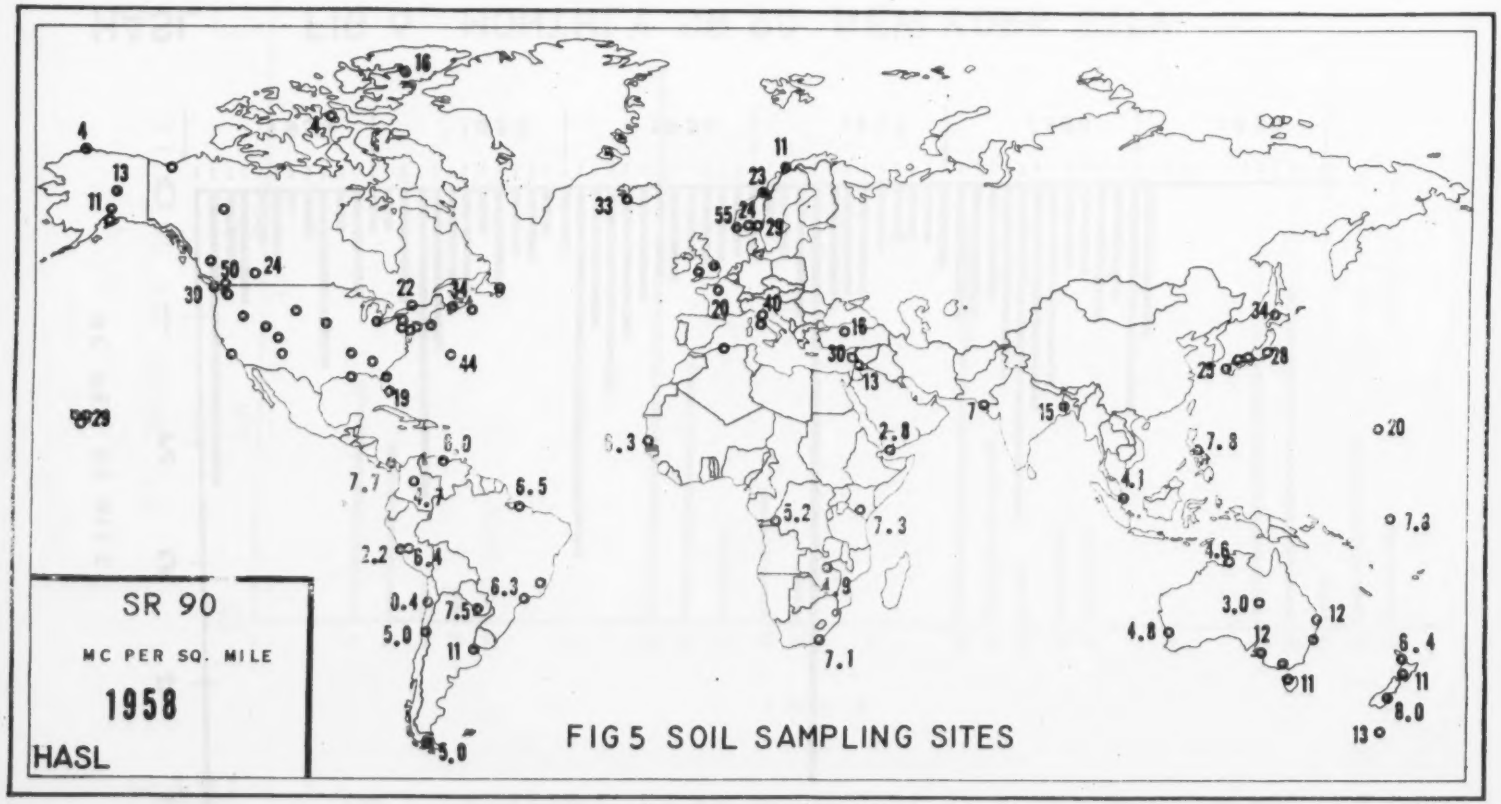
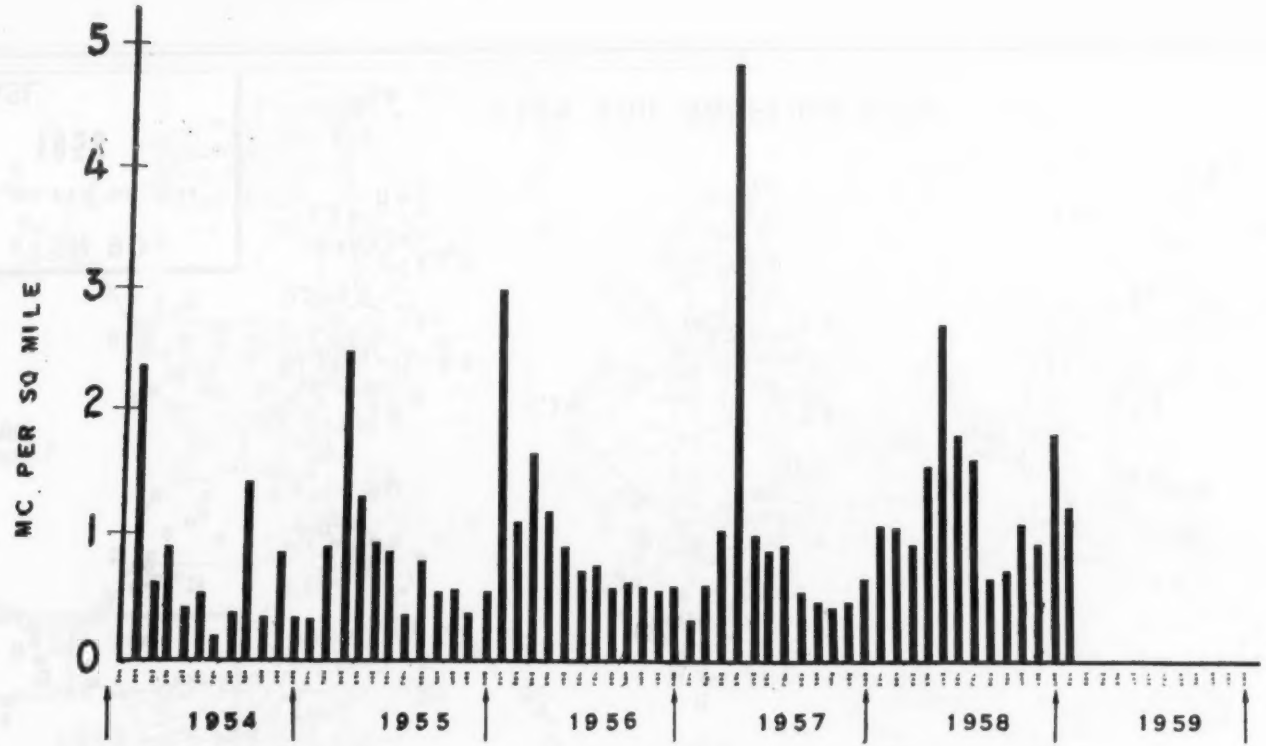
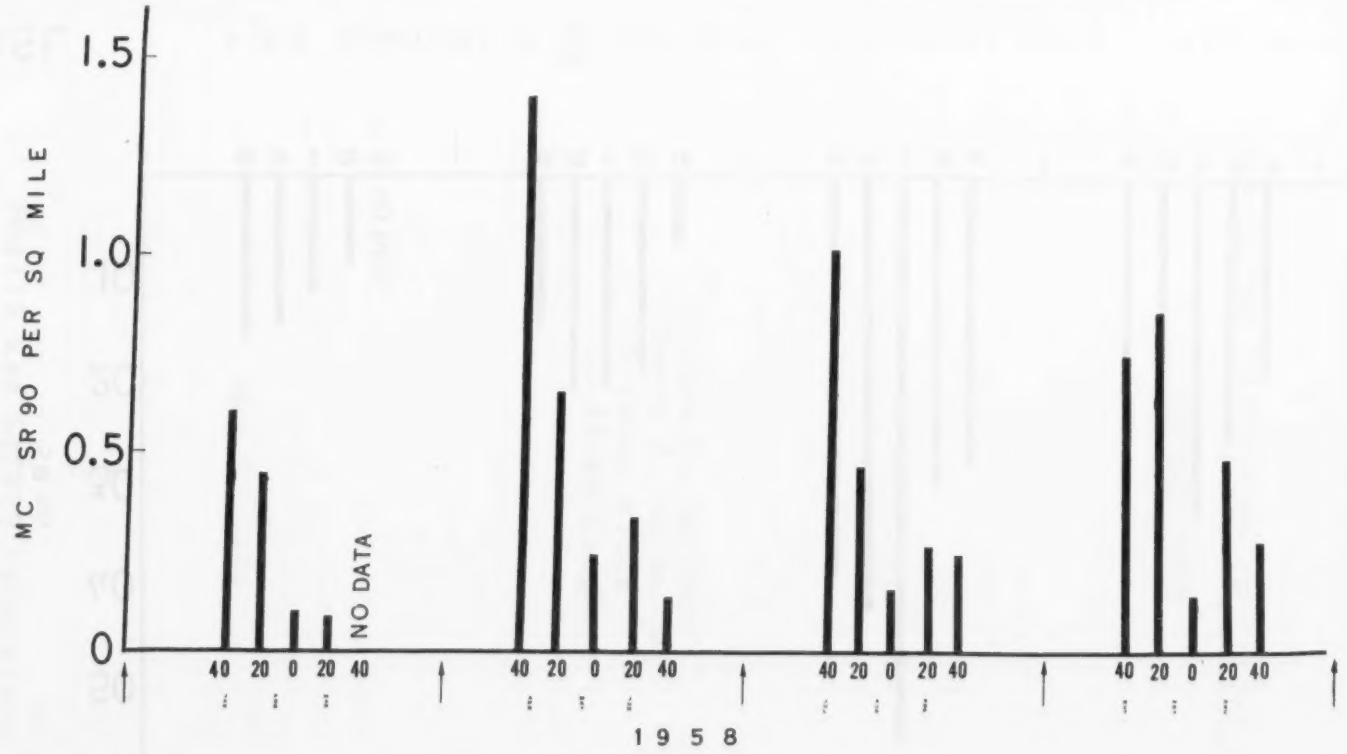


FIG 5 SOIL SAMPLING SITES

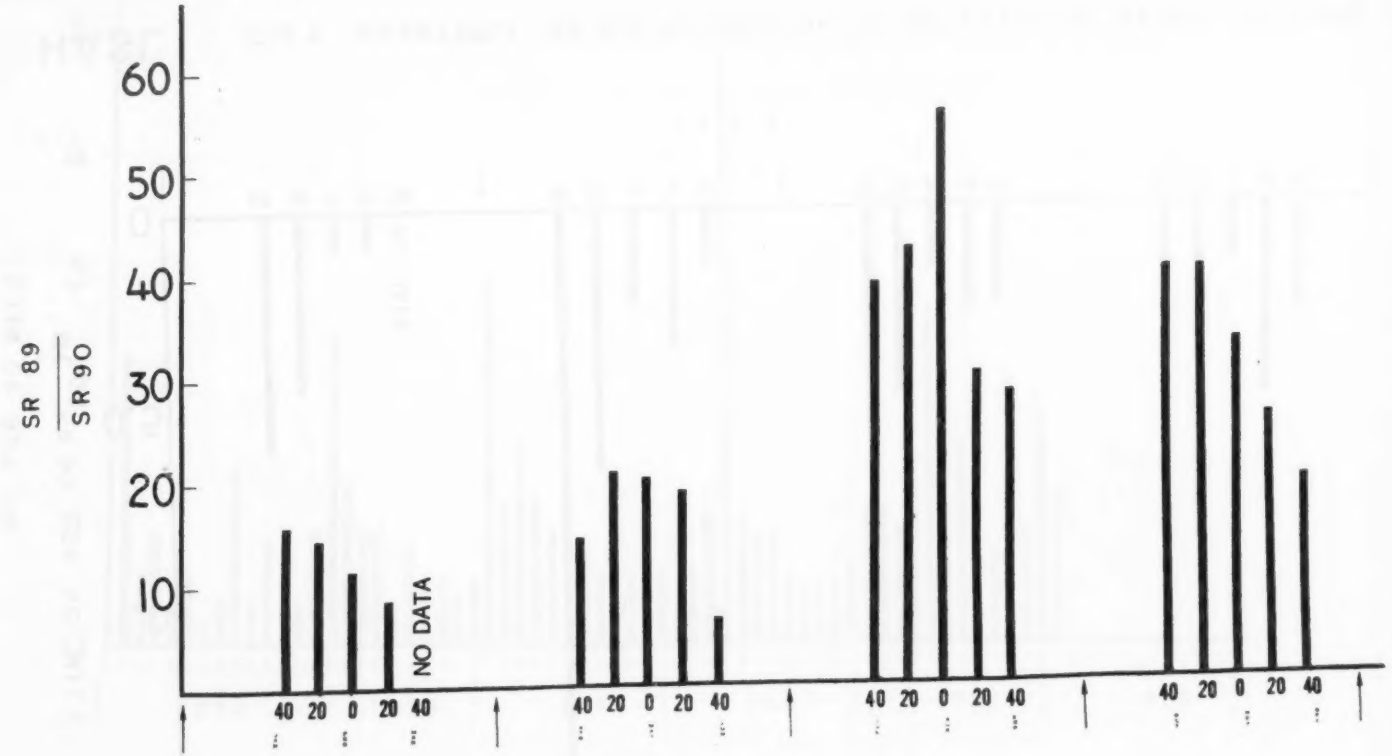


HASL FIG 6 MONTHLY SR 90 NEW YORK CITY

HASL FIG 6 MONTHLY SR 90 NEW YORK CITY



HASL FIG 7 QUARTERLY SR 90 DEPOSITION BY 20° LATITUDE BANDS - '58 POTS



HASL

FIG 8 QUARTERLY SR $\frac{89}{90}$ RATIOS BY 20° LATITUDE BANDS 1958 POTS

HASL FIG 8 QUARTERLY SR $\frac{89}{90}$ RATIOS BY 20° LATITUDE BANDS 1958 POTS

ADDENDUM

DATA ON THE DEPOSITION OF STRONTIUM-90 DURING 1958

John H. Harley
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Stanley Klein
S. Allan Lough

May 1, 1959

Health and Safety Laboratory
UNITED STATES ATOMIC ENERGY COMMISSION
New York, N. Y.

This addendum has been prepared for attachment to the original report prepared on April 20, 1959. As in any analytical operation, results are being obtained almost daily and it is necessary to set a cut-off limit to prepare data in useable form. All results available up to April 28, 1959 are included here.

The following list indicates the material in this addendum:

1. Errata for the April 20th report.
2. Additional pot data for New York City and a curve indicating the cumulative values through March 1959.
3. A partial listing of the results for U.S. soil samples collected in October 1958.
4. A corrected and extended listing of Pittsburgh rainfall data.
5. A corrected and extended listing of Westwood rainfall data.

ERRATA TO THE APRIL 20TH REPORT

1. The value listed in Table 7 for Des Moines was incorrect. This was caused by an error in data transcription and the correct value is listed with other U. S. locations in the attached table.

2. An error was made in the cumulative Strontium-90 value for Pittsburgh rain collections in Table 4. The error was made in the addition for November 15, 1958. This has been corrected and a new listing is attached.

3. There was an error in the cumulative Strontium-90 value for Westwood rain collections in Table 5. This was made in the addition for November 3, 1958. This has been corrected and the proper values are listed in the attached table.

4. Explanatory material was omitted from the heading for Table 9. This table represents monthly Tungsten-185 fallout values grouped by 20° latitude bands.

5. Explanatory material was omitted from the heading for Table 10. This table represents the monthly Tungsten-185 to Strontium-90 ratios grouped by 20° latitude bands.

New York City Pots

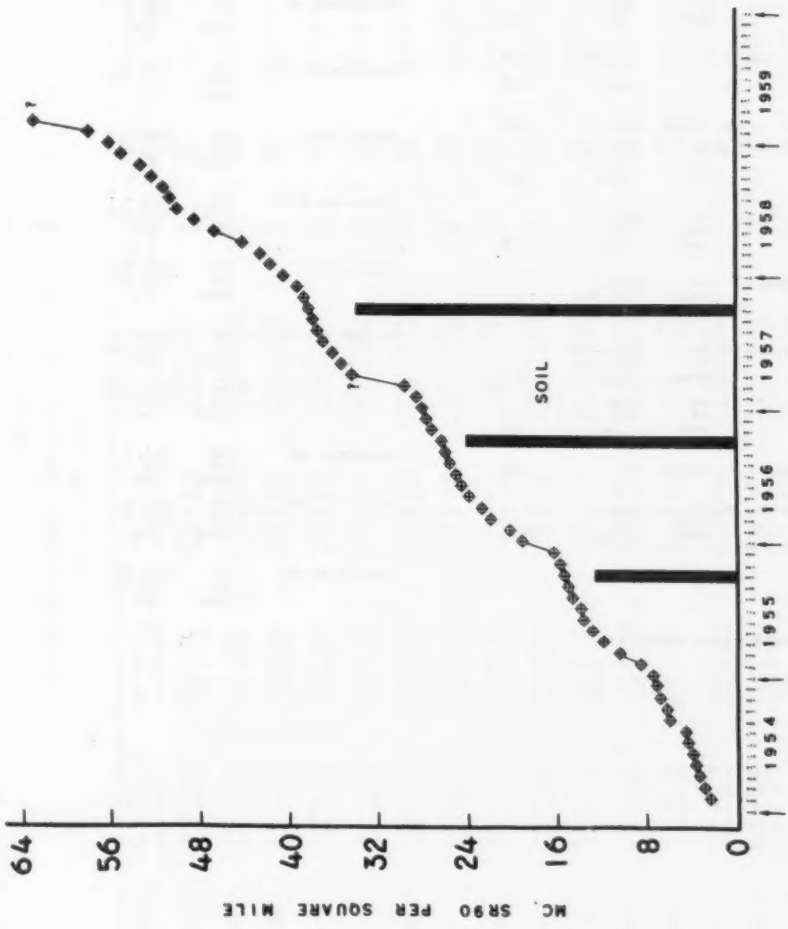
Two additional values for Strontium-90 fallout in New York City were obtained. These values were 1.7 millicuries per square mile for February 1959 and a tentative value of 5.0 millicuries per square mile for March 1959. This latter must be listed as a tentative value since complete checking has not been possible as yet.

Where there is some confirming evidence from other locations of a similar rise in March, the data are not complete and the results are too speculative to draw conclusions at this time.

The cumulative pot values for New York City have been plotted in Fig. 9. Question marks indicate two questionable values, April 1957 and March 1959. The former represented an average of duplicates of 6.66 and 2.95 millicuries per square mile, and the latter value has not yet been confirmed.

Soil analyses have been shown where available. The cumulative pot values should be higher than the soil values, since no allowance has been made for the decay of Strontium-90.

Unfortunately, the soil sampling site used in 1955, 1956, and 1957 was paved over before the 1958 collection. The new site is not comparable, and the two depth measurements give indication of the soil having been disturbed with consequent loss of Strontium-90.



HASL FIG 9 CUMULATIVE SR 90 NEW YORK CITY POTS

TABLE 7

1958 U. S. Soils - sampled October 1958 by HASL

The collected soils were sent directly to Beltsville for preparation. Aliquots were sent to HASL as blind duplicates. Since some of the duplicates have not been completed, the total figures for some sites are not to be considered final.

Site		depth in inches	mc Sr^{90}/mi^2	mc Sr^{90}/mi^2 per in. ppt'n.
Seattle, Wash.	A	0-2	20.6, •	
		2-$8\frac{1}{2}$	12.9, •	
		total	33.5	0.14
" "	B	0-2	18.6, •	
		2-8	$7.\frac{1}{4}$, •	
		total	26.1	0.13
Rapid City, S.D.	A	0-7-$3/4$	73.9, 76.0	0.78
" " "	B	0-7	72.5, •	0.69
Boise, Id.	A	0-8-$3/4$	35.6, •	0.50
" "	B	0-2	17.9, •	
		2-8	23.4, •	
		total	41.3	0.59
Rochester, N. Y.		0-2	25.4, •	
		2-$8\frac{1}{2}$	7.6, •	
		total	33.0	0.18
Detroit, Mich.		0-2	24.0, •	
		2-8-$3/4$	14.9, 16.1	
		total	39.5	0.23
Binghamton, N.Y.	A	0-2	26.3, 23.6	
		2-8	15.3, 15.8	
		total	40.5	0.19
" "	B	0-2	19.2, •	
		2-8	20.2, •	
		total	39.4	0.18
Des Moines, Ia.		0-8-$3/4$	55.7, •	0.37
Salt Lake City, Ut.		0-2	60.4, •	
		2-$7\frac{1}{2}$	17.5, •	
		total	78.0	0.82

Site	depth in inches	mc Sr^{90}/mi^2	mc Sr^{90}/mi^2 per in. ppt'n.
New York, N. Y.	0-2	16.3, 16.2	
	2-9	20.3, •	
	total	36.6	0.16
Philadelphia, Pa.	0-2	25.7, 26.8	
	2-8	17.7, •	
	total	44.0	0.18
Grand Junction, Colo.	0-2	30.0, 27.7	
	2-$8\frac{1}{2}$	9.7, 10.5	
	total	38.9	0.75
Memphis, Tenn.	0-2	25.2, 24.6	
	2-8	11.7, 12.0	
	total	36.8	0.11
Albuquerque, N. M.	0-2	9.9, •	
	2-$8\frac{1}{2}$	18.2, 15.6	
	total	26.8	0.68
Atlanta, Ga.	0-2	23.8, 23.1	
	2-8	11.1, 12.8	
	total	36.9	0.14
Los Angeles, Calif. A	0-2	11.9, 11.4	
	2-7	5.4, 4.4	
	total	16.6	0.25
" " B	0-2	10.4, 9.3	
	2-9	11.6, •	
	total	21.4	0.29
New Orleans, La. A	0-2	18.1, •	
	2-8	10.8, •	
	total	28.9	0.09
" " " B	0-2	21.2, •	
	2-8	18.2, •	
	total	39.4	0.11
Jacksonville, Fla.	0-2	26.1, 26.3	
	2-8	9.6, 10.1	
	total	36.0	0.12

• Blind duplicate is not completed.

Table 4 - Cont'd.

Table 4 - Cont'd.

PRECIPITATION COLLECTIONS - Pittsburgh, Pennsylvania - Cont'd.

Collector Area: 2.58 ft²

Sampling Period from	to	At Midpoint of Sampling Period: mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	mc Sr^{90}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958									
10-23	10-25	2.64 ± 0.12	10.3 ± 1.1	0.85 ± 0.16	0.061 ± 0.006	43	169	34.58 ± 0.25	0.21
		2.66 ± 0.13	7.4 ± 0.4	0.79 ± 0.15	0.064 ± 0.005	42	116		0.21
10-25	10-26	2.07 ± 0.10	6.6 ± 0.3	0.73 ± 0.14	0.046 ± 0.005	45	143	34.63 ± 0.25	0.21
		2.03 ± 0.16	7.1 ± 0.4	0.54 ± 0.10	0.048 ± 0.005	42	148		0.21
10-26	10-28	3.69 ± 0.16	12.2 ± 0.6	0.93 ± 0.14	0.087 ± 0.006	42	140	34.72 ± 0.25	0.28
		3.71 ± 0.18	13.0 ± 0.8	1.13 ± 0.15	0.086 ± 0.005	43	151		0.28
10-28	11-2	0.67 ± 0.07	2.39 ± 0.16	0.29 ± 0.09	0.020 ± 0.005	34	120	34.74 ± 0.25	0.02
		0.59 ± 0.08	lost	0.32 ± 0.10	0.018 ± 0.003	33	—		0.02
11-2	11-3	5.02 ± 0.35	11.7 ± 0.5	1.36 ± 0.14	0.089 ± 0.006	56	131	34.82 ± 0.25	0.31
		5.28 ± 0.35	9.8 ± 0.4	lost	0.079 ± 0.006	67	124		0.31
11-3	11-6	0.40 ± 0.03	0.58 ± 0.04	0.31 ± 0.09	0.004 ± 0.002	100	145	34.82 ± 0.25	0.02
		0.46 ± 0.04	1.37 ± 0.07	0.19 ± 0.09	0.005 ± 0.003	92	274		0.02
11-6	11-9	3.19 ± 0.13	2.96 ± 0.15	0.82 ± 0.08	0.075 ± 0.005	43	39	34.90 ± 0.25	0.13
		2.88 ± 0.15	5.12 ± 0.24	0.73 ± 0.13	0.071 ± 0.004	41	72		0.13
11-9	11-10	3.47 ± 0.19	4.43 ± 0.22	1.00 ± 0.16	0.083 ± 0.006	42	53	34.97 ± 0.25	0.30
		3.37 ± 0.16	3.34 ± 0.26	0.29 ± 0.15	0.066 ± 0.004	51	51		0.30
11-10	11-15	3.65 ± 0.16	8.0 ± 0.4	1.65 ± 0.13	0.109 ± 0.008	33	73	35.07 ± 0.25	0.25
		3.38 ± 0.30	6.7 ± 0.4	1.52 ± 0.14	0.097 ± 0.013	35	69		0.25
11-15	11-16	0.40 ± 0.03	2.20 ± 0.20	0.74 ± 0.16	0.009 ± 0.004	44	244	35.08 ± 0.25	trace
		0.36 ± 0.05	1.22 ± 0.09	0.30 ± 0.09	0.017 ± 0.003	21	72		trace
11-16	11-17	0.67 ± 0.04	1.21 ± 0.16	0.34 ± 0.07	0.012 ± 0.003	56	101	35.09 ± 0.25	0.03
		0.60 ± 0.05	1.35 ± 0.12	0.24 ± 0.08	0.014 ± 0.008	43	96		0.03
11-17	11-18	0.21 ± 0.05	1.03 ± 0.06	0.34 ± 0.08	0.016 ± 0.003	57	64	35.11 ± 0.25	0.04
		0.86 ± 0.07	1.17 ± 0.05	0.18 ± 0.09	0.023 ± 0.003	37	51		0.04
11-18	11-19	2.86 ± 0.12	1.57 ± 0.07	lost	0.099 ± 0.004	48	27	35.17 ± 0.25	0.19
		2.72 ± 0.14	2.35 ± 0.11	0.36 ± 0.08	0.059 ± 0.005	46	40		0.19
11-19	11-24	1.24 ± 0.06	1.57 ± 0.07	1.01 ± 0.25	0.043 ± 0.005	29	37	35.22 ± 0.25	0.02
		1.14 ± 0.08	1.51 ± 0.12	0.87 ± 0.10	0.046 ± 0.018	25	33		0.02
11-24	11-26	0.82 ± 0.04	0.94 ± 0.06	0.42 ± 0.15	0.026 ± 0.006	32	36	35.25 ± 0.25	0.02
		0.79 ± 0.04	0.86 ± 0.06	0.54 ± 0.25	0.033 ± 0.006	24	26		0.02
11-26	11-29	3.45 ± 0.15	1.99 ± 0.12	0.59 ± 0.26	0.080 ± 0.006	43	25	35.32 ± 0.25	0.98
		3.04 ± 0.16	2.72 ± 0.13	2.48 ± 0.25	0.073 ± 0.006	42	37		0.98

Table 4 - Cont'd.

PRECIPITATION COLLECTIONS - Pittsburgh, Pennsylvania - Cont'd.

Collector Area: 2.58 ft^2

Sampling Period from	to	At Midpoint of Sampling Period: mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	mc Sr^{90}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958									
11-29	12-4	2.75 ± 0.13	1.93 ± 0.18	1.45 ± 0.13	0.074 ± 0.009	37	26	35.43 ± 0.25	0.26
		4.07 ± 0.20	2.53 ± 0.11	1.89 ± 0.14	0.130 ± 0.016	31	19		0.26
12-4	12-6	5.10 ± 0.05	2.95 ± 0.14	2.78 ± 0.21	0.141 ± 0.007	36	21	35.54 ± 0.25	0.39
		2.11 ± 0.22	1.27 ± 0.09	1.09 ± 0.14	0.069 ± 0.005	31	18		0.39
12-6	12-9	2.76 ± 0.18	2.12 ± 0.10	1.28 ± 0.12	0.081 ± 0.005	34	26	35.63 ± 0.25	0.13
		4.96 ± 0.35	3.23 ± 0.45	2.14 ± 0.16	0.118 ± 0.013	42	27		0.13
12-9	12-14	1.01 ± 0.06	0.56 ± 0.08	1.51 ± 0.12	0.044 ± 0.008	23	13	35.68 ± 0.25	0.08
		0.92 ± 0.06	0.45 ± 0.06	1.41 ± 0.13	0.053 ± 0.006	17	8		0.08
12-14	12-17	0.93 ± 0.15	0.48 ± 0.04	1.56 ± 0.12	0.029 ± 0.004	32	17	35.71 ± 0.25	trace
		0.74 ± 0.05	0.47 ± 0.06	1.23 ± 0.13	0.031 ± 0.004	24	15		trace
12-17	12-20	3.88 ± 0.17	1.31 ± 0.09	1.86 ± 0.12	0.091 ± 0.011	43	14	35.81 ± 0.25	0.21
		3.77 ± 0.18	1.06 ± 0.09	1.85 ± 0.12	0.108 ± 0.010	35	10		0.21
12-20	12-23	3.57 ± 0.18	0.75 ± 0.08	0.97 ± 0.09	0.082 ± 0.007	44	9	35.90 ± 0.25	0.11
		2.89 ± 0.13	0.65 ± 0.06	1.29 ± 0.11	0.097 ± 0.004	30	7		0.11
12-23	12-31	0.74 ± 0.07	0.18 ± 0.04	1.15 ± 0.11	0.023 ± 0.003	32	8	35.92 ± 0.25	dry
		0.73 ± 0.05	0.11 ± 0.04	1.15 ± 0.11	0.022 ± 0.004	33	5		dry

Table 4 - Cont'd.

PRECIPITATION COLLECTIONS - Pittsburgh, Pennsylvania - Cont'd.

Collector Area : 2.58 ft^2

Sampling Period from	to	At Midpoint of Sampling Period: mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	mc Sr^{90}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958									
12-31	1-2-59	3.9 ± 0.4 4.2 ± 0.3	0.74 ± 0.08 0.72 ± 0.08	1.59 ± 0.12 1.18 ± 0.11	0.093 ± 0.007 0.086 ± 0.007	42 49	8.0 8.4	36.01	0.66
1959									
1-2	1-6	0.85 ± 0.05 0.96 ± 0.09	0.11 ± 0.03 0.12 ± 0.04	0.62 ± 0.10 0.55 ± 0.09	0.023 ± 0.003 0.021 ± 0.006	37 46	4.8 5.7	36.04	trace
1-6	1-11	1.18 ± 0.12 1.06 ± 0.08	0.21 ± 0.09 0.09 ± 0.04	0.96 ± 0.12 0.92 ± 0.13	0.040 ± 0.008 0.029 ± 0.009	30 36	5.2 3.1	36.07	0.11
1-11	1-18	9.0 ± 0.4 9.5 ± 0.4	1.16 ± 0.05 0.95 ± 0.05	4.55 ± 0.3 4.40 ± 0.3	0.275 ± 0.012 0.256 ± 0.013	33 37	4.2 3.7	36.34	1.13
1-18	1-20	7.0 ± 0.3 8.8 ± 0.5	0.52 ± 0.03 0.62 ± 0.04	2.02 ± 0.14 1.48 ± 0.12	0.248 ± 0.012 0.207 ± 0.011	28 42	2.1 3.0	36.56	0.65
1-20	1-25	8.3 ± 0.3 7.8 ± 0.6	0.67 ± 0.04 0.60 ± 0.04	2.55 ± 0.15 2.08 ± 0.14	0.242 ± 0.014 0.214 ± 0.011	34 36	2.8 2.8	36.79	0.99
1-25	2-1	9.3 ± 0.4 10.4 ± 0.4	0.46 ± 0.03 0.54 ± 0.03	2.04 ± 0.14 1.99 ± 0.14	0.335 ± 0.016 0.305 ± 0.016	28	1.4	37.11	0.47
2-1	2-7	1.31 ± 0.15 1.18 ± 0.03	0.05 ± 0.02 0.05 ± 0.02	0.31 ± 0.09 0.37 ± 0.08	0.153 ± 0.008 0.123 ± 0.011	8.6 9.6	0.32 0.40	37.25	0.25
2-7	2-8	6.2 ± 0.3 6.0 ± 0.3	0.16 ± 0.03 0.18 ± 0.04	0.46 ± 0.09 0.42 ± 0.09	0.266 ± 0.013 0.226 ± 0.011	23 26	0.60 0.79	37.50	0.09
2-8	2-10	13.8 ± 0.5 16.9 ± 0.9	0.42 ± 0.03 0.63 ± 0.04	2.78 ± 0.17 2.49 ± 0.15	0.546 ± 0.025 0.581 ± 0.026	25 29	0.76 1.1	38.06	1.23

Table 4 - Cont'd.

PRECIPITATION COLLECTIONS - Pittsburgh, Pennsylvania - Cont'd.

Collector Area: 2.58 ft^2

Sampling from	Period to	At Midpoint of Sampling Period: mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	mc Sr^{90}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1959									
2-10	2-15	5.06 ± 0.65	0.50 ± 0.11	0.96 ± 0.06					
		4.83 ± 0.18	0.22 ± 0.05	0.73 ± 0.06	0.204 ± 0.009	24	1.1		
2-15	2-18	2.60 ± 0.12	0.13 ± 0.03	0.88 ± 0.07					
		2.42 ± 0.15	0.10 ± 0.02	0.46 ± 0.06	0.121 ± 0.008	20	0.8		
2-18	2-24	6.21 ± 0.26	0.14 ± 0.05	0.84 ± 0.06					
		5.92 ± 0.24	0.18 ± 0.04	0.76 ± 0.07	0.239 ± 0.020	24	0.8		
2-24	3-1	4.05 ± 0.15	0.10 ± 0.03	0.41 ± 0.05					
		2.85 ± 0.12	0.06 ± 0.02	0.46 ± 0.06	0.178 ± 0.008	16	0.3		
3-1	3-3	1.87 ± 0.10	0.07 ± 0.02	0.33 ± 0.05	0.087 ± 0.006	21	0.8		
		1.43 ± 0.18	<0.03	0.23 ± 0.04	0.085 ± 0.006	17	-		
3-3	3-5	1.24 ± 0.06	<0.03	0.27 ± 0.04	0.073 ± 0.007	17			
		0.96 ± 0.10	<0.05	0.33 ± 0.05	0.060 ± 0.007	16			
3-5	3-6	4.87 ± 0.18	0.10 ± 0.03	0.59 ± 0.05	0.234 ± 0.010	21	0.4		
		5.07 ± 0.20	0.07 ± 0.02	0.36 ± 0.05	0.244 ± 0.012	21	0.3		
3-6	3-8	0.55 ± 0.06	<0.03	0.21 ± 0.03	0.035 ± 0.005	16			
		0.85 ± 0.05	<0.03	0.40 ± 0.04	0.060 ± 0.007	14			

Table 5 - Cont'd.

Table 2 - Cont'd.

PRECIPITATION COLLECTIONS - Westwood, New Jersey

Sampling Period from	to	At Midpoint of Sampling Period: mc Sr^{90}/mi²	mc Sr^{89}/mi²	mc Ba^{140}/mi²	mc Y^{185}/mi²	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi²	ppt'n. in inches
1958									
10-22	10-23	0.121 ± 0.005	3.57 ± 0.02	4.09 ± 0.07	lost	29.5	33.8	9.14 ± 0.36	1.59
		0.173 ± 0.005	5.21 ± 0.02	4.92 ± 0.02	6.52 ± 0.04	30.1	28.4		1.59
10-23	10-27	---- Lost due to defect in collection pot ----							2.40
		0.616 ± 0.006	36.4 ± 0.5	156 ± 1	13.9 ± 0.1	59.0	253.2	9.76 ± 0.36	2.40
10-27	10-29	0.067 ± 0.004	3.95 ± 0.05	17.3 ± 0.5	1.26 ± 0.02	58.9	258.2	9.83 ± 0.36	0.09
		0.077 ± 0.004	3.56 ± 0.04	13.3 ± 0.2	1.38 ± 0.01	46.2	172.8		0.09
10-29	11-3	0.275 ± 0.006	12.6 ± 0.1	32.3 ± 0.3	5.73 ± 0.02	45.8	117.0	10.10 ± 0.36	0.72
		0.267 ± 0.006	12.2 ± 0.1	27.9 ± 0.1	8.29 ± 0.05	45.6	104.4		0.72
11-3	11-10	0.245 ± 0.005	8.40 ± 0.07	22.9 ± 0.3	5.61 ± 0.04	34.2	93.4	10.34 ± 0.36	0.32
		0.233 ± 0.004	8.33 ± 0.07	18.6 ± 0.2	6.75 ± 0.04	35.7	79.8		0.32
11-10	11-18	0.453 ± 0.014	16.4 ± 0.1	40.5 ± 0.4	6.68 ± 0.05	36.2	89.4	10.73 ± 0.36	0.70
		0.333 ± 0.006	16.8 ± 0.1	38.0 ± 0.3	8.01 ± 0.04	50.4	114.1		0.70
11-18	11-19	0.021 ± 0.003	0.66 ± 0.02	1.43 ± 0.03	0.99 ± 0.01	31.5	68.7	10.76 ± 0.36	0.09
		0.025 ± 0.003	0.80 ± 0.02	1.53 ± 0.03	0.70 ± 0.005	31.7	60.7		0.09
11-19	11-26	0.131 ± 0.004	4.16 ± 0.05	6.54 ± 0.10	3.00 ± 0.02	32	50	10.98 ± 0.37	0.12
		0.127 ± 0.003	4.28 ± 0.05	5.65 ± 0.11	3.08 ± 0.03	34	44		0.12
11-26	12-1	0.564 ± 0.006	18.5 ± 0.1	19.1 ± 0.1	16.9 ± 0.10	33	34	11.43 ± 0.37	2.30
		0.520 ± 0.006	20.1 ± 0.01	20.7 ± 0.2	17.1 ± 0.10	39	40		
12-1	12-4	0.145 ± 0.004	5.25 ± 0.05	4.95 ± 0.08	3.27 ± 0.03	36	34	11.58 ± 0.37	0.68
		0.162 ± 0.004	5.36 ± 0.04	4.59 ± 0.08	3.83 ± 0.03	33	28		0.68
12-4	12-8	0.087 ± 0.003	3.17 ± 0.03	3.35 ± 0.11	2.39 ± 0.02	37	39	11.67 ± 0.37	0.16
		0.096 ± 0.003	3.11 ± 0.03	2.23 ± 0.09	1.84 ± 0.04	32	23		0.16
12-8	12-10	0.066 ± 0.007	2.91 ± 0.04	2.78 ± 0.05	1.84 ± 0.02	44	42	11.75 ± 0.37	0.20
		0.095 ± 0.003	3.20 ± 0.04	2.63 ± 0.10	1.71 ± 0.02	34	28		0.20
12-10	12-15	0.027 ± 0.003	1.11 ± 0.02	1.39 ± 0.13	1.38 ± 0.03	41	52	11.78 ± 0.37	0.02
		0.043 ± 0.004	1.16 ± 0.03	1.09 ± 0.10	1.10 ± 0.03	27	25		0.02
12-15	12-23	≤0.0042	0.31 ± 0.01	0.43 ± 0.04	0.46 ± 0.26	≥73	≥102	11.78 ± 0.37	dry
		≤0.0045	0.29 ± 0.02	0.60 ± 0.08	0.26 ± 0.01	≥65	≥133		dry
12-23	12-30	0.110 ± 0.004	3.50 ± 0.03	1.47 ± 0.04	1.00 ± 0.01	32	13	11.89 ± 0.37	0.22
		0.105 ± 0.004	3.59 ± 0.03	1.27 ± 0.03	0.84 ± 0.01	34	12		0.22

Table 5 - Cont'd.

PRECIPITATION COLLECTIONS - Westwood, New Jersey

Sampling Period from	to	At Midpoint of Sampling Period: mc Sr^{90}/mi^2	mc Sr^{89}/mi^2	mc Ba^{140}/mi^2	mc W^{185}/mi^2	Sr^{89}/Sr^{90}	Ba^{140}/Sr^{90}	Cumulative mc Sr^{90}/mi^2	ppt'n. in inches
1958									
12-30	1-2-59	0.441 ± 0.005 0.428 ± 0.006	15.8 ± 0.1 15.4 ± 0.1	4.59 ± 0.11 4.82 ± 0.18	4.12 ± 0.08 4.06 ± 0.08	36 36	10 11	12.33	1.43
1959									
1-2	1-5	≤0.011 0.019 ± 0.003	0.480 ± 0.024 0.324 ± 0.022	0.603 ± 0.035 0.407 ± 0.026	0.905 ± 0.009 0.558 ± 0.006	17	21	12.35	0.01
1-5	1-12	≤0.007 ≤0.009	0.104 ± 0.025 0.091 ± 0.023	0.331 ± 0.061 0.364 ± 0.074	0.292 ± 0.006 0.174 ± 0.003			12.36	dry
1-12	1-13	0.038 ± 0.003 0.024 ± 0.002	1.16 ± 0.02 0.764 ± 0.014	0.470 ± 0.097 0.336 ± 0.056	0.452 ± 0.009 0.509 ± 0.010	31 32	12 14	12.39	0.01
1-13	1-17	0.423 ± 0.006 0.455 ± 0.007	13.8 ± 0.1 12.4 ± 0.1	2.27 ± 0.006 2.23 ± 0.006		33 27	5 5	12.83	0.43
1-17	1-22	0.401 ± 0.020 0.415 ± 0.021	10.6 ± 0.1 10.7 ± 0.1	1.84 ± 0.05 1.51 ± 0.04		26 26	5 4	13.23	0.63
1-22	1-27	0.079 ± 0.006 0.056 ± 0.006	1.67 ± 0.02 1.10 ± 0.02	0.345 ± 0.010 0.196 ± 0.028		21 20	4 3	13.30	0.10
1-27	1-30	0.143 ± 0.004 0.128 ± 0.005	3.32 ± 0.05 3.52 ± 0.05	0.459 ± 0.008 0.424 ± 0.002		23 28	3.2 3.3	13.44	0.05
1-30	2-4	0.305 ± 0.006 0.306 ± 0.004	7.98 ± 0.03 8.74 ± 0.03	0.873 ± 0.019 0.754 ± 0.018		26 28	2.9 2.5	13.74	0.55
2-4	2-12	0.545 ± 0.011 0.607 ± 0.012	15.66 ± 0.15 15.82 ± 0.14	1.37 ± 0.02 1.69 ± 0.02		28 26	2.5 2.8	14.32	1.00
2-12	2-13	0.049 ± 0.003 0.053 ± 0.003	1.30 ± 0.04 1.42 ± 0.04	0.200 ± 0.014 0.209 ± 0.005		26 27	4.1 3.9	14.37	0.10
2-13	2-16	0.107 ± 0.005 0.096 ± 0.004	2.55 ± 0.03 2.46 ± 0.03	0.220 ± 0.008 0.276 ± 0.011		24 26	2.0 2.9	14.47	0.41
2-16	2-19	0.102 ± 0.004 0.084 ± 0.003	1.80 ± 0.04 1.71 ± 0.04	0.343 ± 0.020 0.205 ± 0.008		18 20	3.4 2.4	14.56	0.04
2-19	2-24	0.142 ± 0.003 0.212 ± 0.004	3.41 ± 0.05 3.86 ± 0.05	0.344 ± 0.011 0.321 ± 0.016		24 1d	2.4 1.5	14.74	0.09

CURRENT INFORMATION ON THE RADIOACTIVITY OF THE AIR

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The U.S. Naval Research Laboratory program of atmospheric radioactivity studies consists of two parts: (a) a program of the daily measurement of the natural radioactive materials (decay products of radon and thoron) and of gross fission products in the air at a number of sites, principally in the Western Hemisphere, and (b) a unified network of stations along the 80th meridian (west) which collect daily samples of the radioactivity in the air for later analysis at NRL. This latter program has been a part of the International Geophysical Year Program on atmospheric nuclear radiation; it is being continued through December 1959 as part of the International Geophysical Cooperation Program which has superceded the IGY.

It should be made clear at this point that no measurements of "fallout" as such are made in this program but only measurements of the concentrations of radioactive matter in the air. The NRL program was organized to obtain needed information in this area which was not covered by the usual fallout monitoring networks. However, there must be some relation between the air concentration of fission products and their deposition on the ground by impaction, rainout, or fallout processes. A knowledge of the air concentrations of these nuclear debris as well as of the existing meteorological conditions is required for any interpretation of these processes. From a knowledge of the amount of fission products in the air at a representative number of sites, it should be possible to determine the total quantity of fission products in the troposphere. Furthermore, changes in this load or burden with time are related to the depletion rate of the stratospheric burden, the hemispheric mixing rate, seasonal changes in meteorological factors, and the injection rate by new nuclear explosions. The determination of the background radioactivity due to decay products of radon and thoron in the air gives one baseline for evaluating the relative hazard associated with the addition of new radioactive matter into man's environment (1, 2).

The Naval Research Laboratory has made contributions to many phases of the fallout study. The possibility of fractionation of isotopes relative to one another was postulated and proved a number of years ago. The pioneering work on rainfall as a scavenger of radioactivity from the air was performed in the early days (1948) of this project but was discontinued when the fission product background became so high that the filter method of surveillance of atomic explosions became relatively more effective (3). Several years ago a study of the collection of fission debris on cheesecloth indicated that the impaction process was an important mechanism in the deposition of fission products in the absence of rain (4). Further, the stations operated continuously

by us for the past ten years have furnished a record of the progressive changes in the fission product concentration with time -- from the time when their detection was an occasion of great excitement to the present time when they are commonplace.

The first phase of this study employs complete air monitor equipment designed and supplied by the U.S. Naval Research Laboratory and capable of determining the contribution of the natural and fission product activities in the air. This equipment is presently being operated by us at Washington, D.C., and by cooperating groups at Yokosuka, Japan; Kodiak and Wales, Alaska; the South Pole (formerly at Little America); Rio de Janeiro, Brazil; Chacaltaya, Bolivia; and Lima, Peru. Similar equipment is also operated by the U.S. Naval Radiological Defense Laboratory at San Francisco, California. Some of this work has been summarized in recent publications from this Laboratory (1-3, 5). An example of this work is shown in Table 1 where the relative amounts of the major contributors to the radioactivity of the air as determined during 1957 are reported. It is evident that at no location did the fission product activity contribute any appreciable fraction of the total activity. However, the fission product activity has increased noticeably at all sites during the past year. The changes in the activity levels during the period 1955-1958 at Yokosuka, Japan are shown in Table 2. There the fission product activity reached its highest average value during 1958 and has remained high during the first few months of 1959, in keeping with other sites in the Northern Hemisphere.

The second phase of this study, the 80th meridian program, is entirely different in operation, organization, and purpose. It was organized in early 1956 at our suggestion and is a cooperative project of NRL, the U.S. Weather Bureau, the Atomic Energy Commission, the Air Force Cambridge Research Center, and cooperating organizations in Canada and South America. The program is financed jointly by the U.S. Navy and the AEC with some support from the U.S. Air Force.

Simple collections of airborne radioactive debris are made daily on filter paper at each collecting site (Fig. 1) and are forwarded to NRL for gross radioassay and for radiochemical analysis. Some of the samples are passed on to the Air Force for inclusion in their program. Each represents the activity in about 40,000 cubic feet of air. These samples are ashed at 650°C on receipt at NRL, compressed to a 1-inch-diameter disk and counted for β activity on the 14th day following collection. The counters have been calibrated with NBS standards of various β energies and the counts are corrected to disintegrations per minute (assuming an average β energy of 1 Mev). The results are reported monthly to participants in the program and to other interested parties and the information is also forwarded to the IGY data center at Asheville, N.C. The latest monthly report (March 1959) is attached (Appendix A).

The changes in the gross fission product activity of the air can be followed over the last 18 months from a study of the radioactivity profiles shown in Figs. 2-4. The profiles for 1958 are particularly illuminating. From relatively low values in January and February 1958, the activity in the Northern Hemisphere increased markedly following the spring series of nuclear tests in the USSR and peaked at sites located in the region of 25°-40° north latitude. It decreased during July-September even though our Pacific tests (Hardtack, phase I) were taking place, but it responded strongly to the fall series of Russian tests. Again peak activities occurred at 25°-40° north latitude. The activity levels during the past four months, listed in Table 3, indicate that the fission product concentration is remaining at a high level even though all nuclear testing ceased in early November 1958. In fact, the fission product burden in the troposphere of the Northern Hemisphere reached its highest value in February and March of this year. Meanwhile the highest monthly average ever recorded along the 80th meridian appeared at Miami, Florida, during March 1959 (Appendix A).

The situation in the Southern Hemisphere is quite different. The low activity levels of early 1958 increased tremendously following the British test of April 28 at Christmas Island and our tests at the Eniwetok-Bikini area. The activity at several sites in South America exceeded the maximum values in the Northern Hemisphere for the first time on record; however, the total burden of activity in the Northern Hemisphere was approached but not exceeded. Following the cessation of these tests, the activity below the Equator decreased and is continuing to do so. There is no indication of any further massive transfer of activity from the Northern to Southern Hemisphere, though some of the values near the Equator indicate that mixing on a limited scale may be occurring. Results just received from our equipment located at the South Pole indicate the activity there to be about the same as near the tip of South America. This represents a fivefold increase over that recorded in Little America a year earlier.

Because of the limitations of any system based on gross activity measurements, an integral part of this program has been the radiochemical analysis of monthly samples from each of the collecting sites. Through such studies the actual content of Sr^{90}, Cs^{137}, and other isotopes of interest in the samples are determined. One isotope of particular interest is W^{185} (tungsten-185) which was introduced during our Pacific Hardtack tests for use as a tracer for debris from this test series. The results of radiochemical analyses for this isotope in various collections are shown in Table 4. This isotope served to identify the radioactivity appearing in South America as coming from our Hardtack tests. Its detection in these collections also served to mark the rate of spread of the debris along the 80th meridian. There was no detectable W^{185} activity in the air at any site during April 1959. In May it was detected at all sites from Columbia, S.C., to Antofagasta,

Chile. In June it appeared at all sites from Moosonee, Ontario (51°N), to Punta Arenas, Chile (53°S), while in July it appeared at Coral Harbour, N.W.T., Canada (64°N). This would indicate that debris from a single point are not necessarily restricted to a narrow band near the latitude of the collecting site. This is also evident from the gross β measurements (Figs. 3 and 4) which show that activity from the USSR tests in the Arctic appeared in force at the latitudes of Miami and Columbia, S.C. It is of interest that the highest W^{185} concentrations appeared initially at the high altitude sites of Chacaltaya, Bolivia (5220 meters); Huancayo, Peru (3353 meters); Quito, Ecuador (2818 meters); and Bogota, Colombia (2640 meters). Similarly, in Hawaii much higher activities were encounted at Mauna Loa (3394 meters) than at Pearl Harbor (5 meters).

Measurements of the W^{185} in collections made during January 1959 (Table 4) show it was present in substantial quantities in both the Northern and Southern Hemispheres, except for the equatorial region where the activity was low. When this activity (half-life, 74 days) is corrected for decay back to July 1958, it is evident that the contribution of Hardtack debris to the radioactivity of the ground-level air has increased considerably during the period July 1958 to January 1959.

In addition to the analysis for W^{185}, radiochemical determinations are made for the fission products Sr^{89}, Sr^{90} (Y^{90}), Y^{91}, Cs^{137}, Ce^{141}, and Ce^{144}. Some of these data are shown in Figs. 5 and 6, where the latitudinal variations of several of these radioisotopes in March are compared with those in May 1958. Several items of interest will be found in the data. Note that the general profiles for the gross activity and for the individual isotopes (Sr^{90}, Cs^{137}, Ce^{144}, Y^{91}) are very similar. During March the Cs^{137}/Sr^{90} ratio varied from a minimum of 1.7 to a maximum of 3.0 for measurements made at 15 sites along the 80th meridian. During May, the variation was from 1.4 to 5.0, with the highest ratios occurring in South America.

The relative quantities of Y^{91} (57-day half-life) and Ce^{144} (285-day half-life) activities at the various sites indicate in a general way the relative ages of the debris at the different sites. For example, during March the Y^{91} curve lies above that of Ce^{144} in the Northern Hemisphere whereas it is below the Ce^{144} curve in the Southern Hemisphere. This indicates that the debris in the Northern Hemisphere were younger than at the other sites, in part because of the influx of fresh debris from the USSR tests. By May, the situation had changed radically. From Washington, D.C. to Coral Harbour, N.W.T., the Y^{91} activity in the air had decreased through decay until it contributed less to the total than did the Ce^{144}. The situation was reversed in the areas affected by our Pacific tests. As would be expected, those areas which received the largest quantities of Hardtack debris, as indicated by high W^{185} activities (Table 4), showed the greatest increase

in Y^{91} relative to Ce^{144} or other long-lived isotopes, confirming the known freshness of the activity.

Another way of presenting data which indicates relative ages of debris at different sites is shown in Fig. 7, where the ratio of Sr^{90} to gross fission products is plotted against the latitude of the collecting site. Sr^{90} is a minor contributor to the total radioactivity of fresh fission products because of the preponderance of both high- and low-yield isotopes with short half-lives. However, as the debris become older, the relative contribution of the Sr^{90} increases. In Fig. 7 the Sr^{90}/gross fission product ratios are low in the Northern Hemisphere and high in the Southern Hemisphere during the period January-April 1958, indicating that older debris contributed to the radioactivity in the air in South America. It is most interesting that the air around the high-altitude stations in South America contained younger debris than that at the low-altitude stations. The great age of the debris at Punta Arenas at the southern end of South America is understandable in view of its location relative to the nuclear test sites; why the debris at Lima, Peru, are so old is not evident. Above the Equator, the presence of the fresh debris from the Soviet tests of February 23 to March 22, 1958, is evident in that the Sr^{90} contribution to the gross activity decreased markedly during March and April. Analyses are underway on debris collected during later months but are not yet completed. The latest figures on the air concentration of Sr^{90} at sites along the 80th meridian are listed in Table 5. Earlier information is reported in Ref. 6.

The relationship between rainfall and fallout is of great interest since rain is considered to be the principal mechanism by which radioactivity is removed from the air. Some work on this problem was done at NRL a number of years ago (7-9). More recently, a correlation of the gross radioactivity in the air and the rainfall at Miraflores, Panama, has been reported (10). As would be expected, the lowest air concentrations of fission products were obtained during the rainy season. New data on the relation between rainfall and fission products in the air at Panama are shown in Fig. 8. Here the monthly average Sr^{90}, Cs^{137}, and gross fission product activities are plotted against the total rainfall during the month. The increase in the air activity during the period December 1957-March 1958 correlates well with the dry season. The large increase in April must be due at lease in part to the Soviet tests of February 23 to March 22. This is confirmed by the decrease in the amounts of Sr^{90} and Cs^{137} relative to the gross fission products during April as compared to the earlier months. However, there is also evidence of a spring maximum in stratospheric fallout since the Sr^{90}/gross fission product ratio is too high to be representative of fresh debris. It seems that both increased stratospheric fallout and fresh debris are involved. The advent of the rainy season in May resulted in a great increase in the total activity in the air and an apparent increase in the age of the radioactive material. The migration of tropospheric debris to this area was so inhibited by rain that the radioactivity collected was more nearly representative of

stratospheric material. During June, but especially during July, some fresh material from our Hardtack tests did penetrate to this Panama site in spite of the rainy weather. This is shown by the low Sr^{90} and Cs^{137} values relative to the gross activity and also is demonstrated by the presence of W^{185} activity (Table 4).

It was mentioned earlier that data obtained from this 80th meridian program could be used to obtain the tropospheric burden of radioactivity. A naive approach to this has been made by employing the simplifying assumptions that our results are representative of the world-wide distribution of radioactivity, and that our ground-level measurements are representative of the air concentration up to a height of 15 km (49,000 ft). This latter assumption embodies the approximation that the activity per standard cubic meter of air increases exponentially with altitude up to the tropopause, which is qualitatively true. It does not allow for the different heights of the tropopause at high and low latitudes. The results for the gross fission product burden is shown graphically for 1958 in Fig. 9. The influence of the Soviet spring and fall tests is evident in the Northern Hemisphere burden. Likewise, our Pacific tests had a tremendous influence on the Southern Hemipshere burden which was particularly striking because of the low background of fission products there. Our Pacific tests caused only a slight bulge in the Northern Hemisphere curve during July and August; similarly, the British tests of August and September 1958 at Christmas Island caused only a momentary break in the rate of decline of radioactivity in the Southern Hemisphere. Using the same assumptions to calculate the Sr^{90} burden in the troposphere north of the Equator, it was found to have increased from 24 to 57 kilocuries during the period January-April 1958, while in the Southern Hemisphere it declined from about 6 to 3 kilocuries. Similar evaluations of the W^{185} burdens during May, June, and July gave values of about 50, 300, and 720 kilocuries for the Northern Hemisphere and 120, 580, and 530 kilocuries for the Southern Hemisphere.

At this time it is believed worth speculating about the information obtainable from a study of the tropospheric burdens of activity, particularly if the present moratorium on nuclear testing were continued. If no mixing occurs across the Equator and if no fresh injections of radioactive debris are made, the burdens of a long-lived radioisotope such as Sr^{90} should follow independent courses in the two hemispheres as shown in Fig. 10. The rate of decrease in the burden after equilibrium has set in between rate of stratospheric "drip" and rate of deposition would be a measure of the rate of decrease of the stratospheric burden. The actual levels of activity in the two hemispheres would be representative of the debris injected into the stratosphere on either side of the Equator. (This has assumed uniform vertical mixing within the stratosphere and also has ignored seasonal changes which may influence the shapes of the curves).

The more likely situation where limited mixing across the Equator occurs would give an entirely different picture. Here the assumption has been made that the transequatorial mixing rate in the stratosphere has about a 3-year half-life, while the stratospheric deposition process has a half-life of about 7 years. These figures can be determined from measurements of the sort discussed here by determining the rate of convergence of activity burdens in the Northern and Southern Hemisphere, and the rate of decline of the total burden of Sr^{90} (or Cs^{137}, etc.) in the troposphere of the whole globe. Such measurements are meaningful only so long as no fresh debris are added to upset the equilibrium process. It should be noted that this method will not give information on the stratospheric burden of radioactivity. Such information must be determined through long-term measurement of a single rate process, such as the rate of accumulation of Sr^{90} in the soil or the rate of fallout as determined by suitable collection means.

SUMMARY AND CONCLUSIONS

1. The fission product radioactivity of the air increased markedly in the Northern Hemisphere during 1958 as the result of the intensive test program carried out there during this period. It has continued to increase during 1959 as the result of the delayed deposition of debris injected into the stratosphere by the recent Soviet series in the Arctic and the United States series in the Pacific (Hardtack).

2. In spite of the large increase in the radioactivity of nuclear debris in the air, this material still contributes only a small fraction of the total radioactivity of the ground-level air.

3. Radioactive debris injected into the troposphere at any particular site spread rapidly throughout the entire hemisphere but rarely across the Equator in any quantity. An exception to this rule occurred during the Hardtack series in the Pacific when massive quantities were transported to the Southern Hemisphere by winds in the upper troposphere. Because of a quirk of nature, material injected into the Northern Hemisphere air appears along the 80th meridian in highest concentrations in the region of 25°-40° north latitude whether the injection be made in the arctic or tropic region.

4. Radiochemical techniques offer a powerful tool to study the source and age of radioactive debris. When a unique tracer material (for example W^{185}) is present in debris from a single source or injection site, it offers a means of identifying material from this source in the presence of a high background of radioactive products from other sources. Thus, future measurements of W^{185} from our Pacific Hardtack series of tests will enable the movement of this material to be followed for perhaps another year.

5. Fission products in the ground-level air in the Southern Hemisphere are relatively richer in such long-lived isotopes as Cs^{137} and Sr^{90} than in the Northern Hemisphere, indicating a greater age of debris there. This is because fewer nuclear explosions introduce their debris directly into the Southern Hemisphere air; hence older fission products from the stratospheric contribute a larger fraction of the total fission product activity. In estimating the Sr^{90} activity from the measurement of the gross fission product activity of filters, rain water, or gummed films, it is necessary to take into account this latitudinal effect, which will vary in magnitude as additional fresh debris are introduced into the air.

6. Periods of heavy rainfall, such as occur during the rainy season in Panama, cause a general decrease in the concentration of fission products in the air. At Panama, this rain belt apparently, on occasion, has prevented the influx of air from farther north which contained fresher fission debris with the result that the composition of the radioactivity in the ground-level air at Panama more closely resembled that of the stratosphere.

7. The determination of the total burden of radioactivity in the air is possible through measurement of the radioactivity in the air at a representative series of sites. The 80th meridian network, together with a few check points in other areas, appears to give a reasonable cross section or profile of the fission product radioactivity at the earth's surface, and should give basic data suitable for calculating realistic tropospheric burdens of activity. During the next year or two, barring the introduction of fresh nuclear debris into the atmosphere, the changes in the burden of activity (particularly of such long-lived activities as Sr^{90} and Cs^{137}) in the troposphere will give a realistic value for the depletion rate of the stratospheric reservoir of activity and for the transequatorial mixing rate in the stratosphere.

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Table 1
Geographical Distribution of Atmospheric Radioactivity During 1957

	Activity in Micromicrocuries per cubic meter*		
	Radon	Thoron	Fission Products
Washington, D. C.	172	2.3	2.1
Yokosuka, Japan	54	0.48	0.66
Wales, Alaska	16.7	0.14	0.31
Kodiak, Alaska	7.3	0.042	0.16
Little America	1.5	<0.01	0.019

*1 $\mu\mu$ curie/m^3 = 10^{-18} curies/cc

Table 2
Yearly Averages of Radioactivity and Rainfall
at Yokosuka, Japan, 1955-1958

	Year			
	1955	1956	1957	1958
Radon ($\mu\mu c/m^3$)	56	71	54	43
Thoron ($\mu\mu c/m^3$)	0.48	0.50	0.47	0.48
Gross Fission Products ($\mu\mu c/m^3$)	0.35	1.13	0.66	2.96
Rainfall (inches)	66.55	-	76.33	64.77
Days with Rain	148	-	185	184
Percentage fission products*	0.63%	1.58%	1.22%	6.9%

*relative to radon in the air

Table 3
Summary of Recent Measurements of the Gross Fission Product Activity in the Ground Level Air along the 80th Meridian

Site	Radioactivity in d/m per cubic meter of air				
	1958		1959		
	November	December	January	February	March
Thule, Greenland	8.78	10.0	16.2	11.5	13.7
Coral Harbour, N.W.T.	5.53	5.02	7.27	9.5	10.0
Moosonee, Ont.	7.22	4.57	8.45	11.0	10.5
Bedford, Mass.	11.3	8.68	9.85	14.6	14.0
Silver Hill, Md.	12.1	9.25	13.9	15.0	15.2
Columbia, S. C.	16.0	12.9	17.1	17.7	19.2
Miami, Fla.	15.0	13.8	18.9	15.0	24.3
San Juan, P. R.	5.55	6.69	8.64	14.1	9.69
Miraflores, P.C.Z.	1.30	5.10	6.35	14.8	10.7
Bogota, Colombia	0.68	1.89	2.84	7.02	2.72
Quito, Ecuador	0.28	0.35	0.57	0.92	0.54
Guayaquil, Ecuador	-	-	0.38	-	-
Iquitos, Peru	0.18	0.85	1.94	-	1.18
Lima, Peru	0.79	0.63	0.51	0.38	0.26
Huancayo, Peru	0.94	0.58	0.31	0.29	-
Chacaltaya, Bolivia	1.19	0.66	0.42	0.32	0.22
Antofagasta, Chile	1.07	0.88	0.81	0.56	0.38
Porto Alegre, Brazil	0.69	0.64	0.49	0.47	0.60
Santiago, Chile	0.65	0.61	0.51	0.50	0.50
Puerto Montt, Chile	0.32	0.35	0.38	0.44	0.48
Punta Arenas, Chile	0.12	0.13	0.19	0.24	0.18
South Pole	-	-	-	-	0.23*

*Information obtained from NRL monitor equipment

Table 4
Distribution of W^{185} Tracer in the Air Following its Introduction During the U. S. Hardtack Nuclear Tests in the Pacific

	W^{185} Radioactivity in d/m per 100 standard cubic meters							
	April	May	June	July	Sept	Nov	Jan	Mar
Coral Harbour	0.0	0.0	0.0	1.1	-	-	37	*
Moosonee	0.0	0.0	1.0	8.1	-	-	34	*
Washington	0.0	0.0	11	53	-	-	50	*
Columbia	0.0	1.1	20	161	-	-	-	-
Miami	0.0	4.2	23	43	104	61	55	*
Miraflores	0.0	2.7	15	12	-	-	2	*
Bogota	0.0	15	54	47	-	-	-	-
Quito	0.0	12	50	17	-	-	3.6	*
Guayaquil	0.0	1.8	21	20	-	-	-	-
Lima	0.0	0.8	37	27	-	-	8.5	*
Huancayo	0.0	44	88	88	-	-	-	-
Chacaltaya	0.0	35	145	110	-	-	-	-
Antofagasta	0.0	4.3	57	46	43	19	13	3.8
Santiago	0.0	0.0	6.7	21	-	-	9.8	*
Punta Arenas	0.0	0.0	0.8	1.4	-	-	1.6	*

*Scheduled for analysis during May 1959

Table 5
Distribution of Sr^{90} in the Ground-Level Air at Sites
Along the 80th Meridian, January-June 1958

Collection Site	Station Location			Sr^{90} Activity in d/m per 100 s.c.m.*					
	Latitude	Longitude	Altitude(m)	Jan	Feb	Mar	Apr	May	Jun
Coral Harbour	64°12′N	83°22′W	59	-	-	2.7	3.3	1.9	2.5
Moosonee	51°16′N	80°39′W	10	0.96	1.3	2.0	3.7	3.0	4.3
Washington	38°50′N	76°57′W	88	-	2.0	1.6	3.9	5.9	4.4
Columbia	33°57′N	81°07′W	69	1.9	2.8	2.7	5.3	6.9	4.4
Miami	25°49′N	80°17′W	4	2.4	2.2	3.5	4.4	4.6	2.9
Miraflores	9°00′N	79°35′W	10	0.79	0.8	1.5	2.3	0.52	0.17
Bogota	4°37′N	74°04′W	2640	0.39	0.33	0.45	0.39	0.055	**
Quito	0°08′S	78°26′W	2818	0.073	0.070	0.098	0.054	0.038	**
Guayaquil	2°10′S	79°52′W	7	-	0.12	0.086	0.12	0.11	**
Lima	12°06′S	77°01′W	134	0.25	0.29	0.25	0.18	0.10	**
Huancayo	12°07′S	75°20′W	3353	0.17	0.07	0.054	0.080	0.17	0.16
Chacaltaya	17°10′S	68°15′W	5220	0.23	0.18	0.12	0.13	0.36	**
Antofagasta	23°37′S	70°16′W	519	0.49	0.48	0.33	0.31	0.21	0.31
Santiago	33°27′S	70°42′W	520	0.65	0.58	0.34	0.33	0.15	0.13
Punta Arenas	53°08′S	70°53′W	3	0.16	0.26	0.30	0.18	0.11	**

* Standard cubic meters
** Analyses in progress

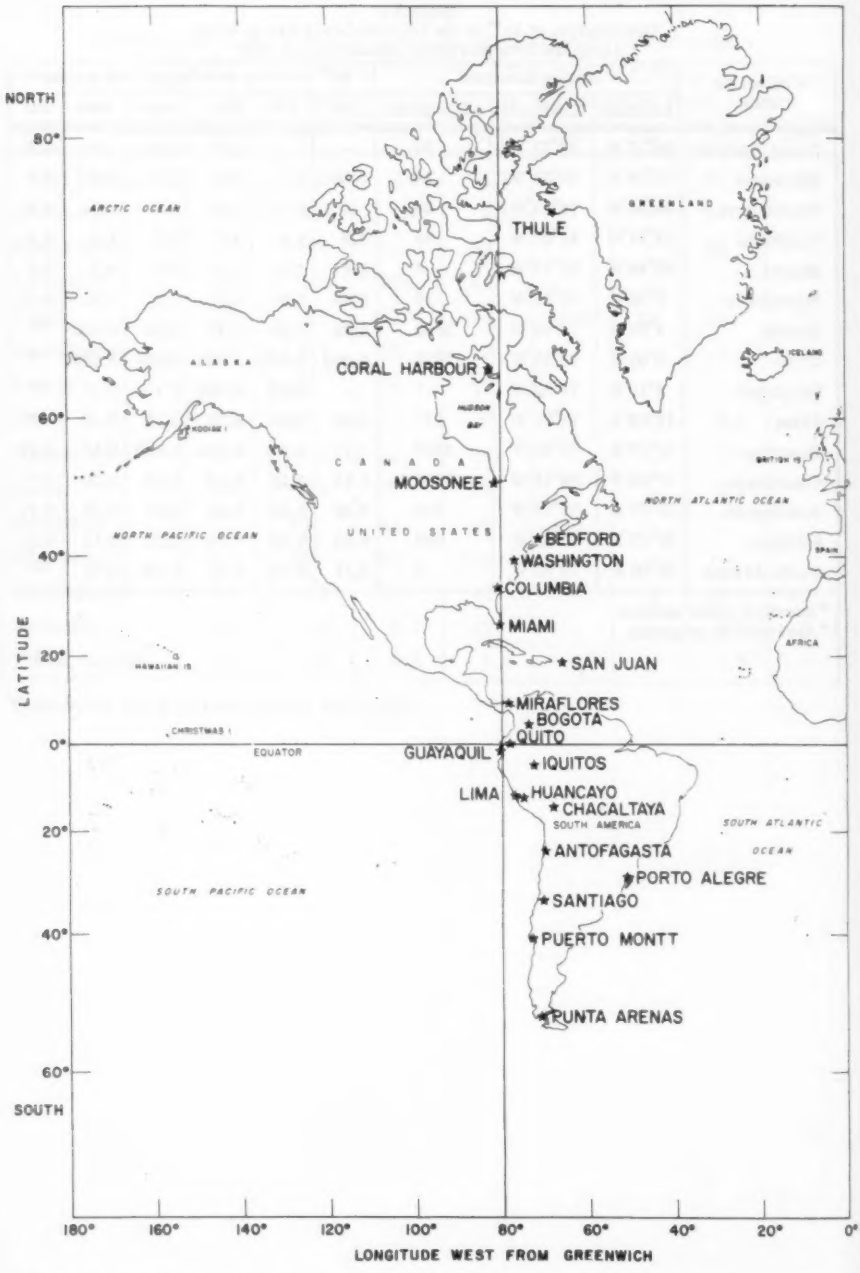

Fig. 1 - Atmospheric radioactivity stations along the 80th meridian

AVERAGE FISSION PRODUCT CONCENTRATION IN D/M PER CUBIC METER OF AIR

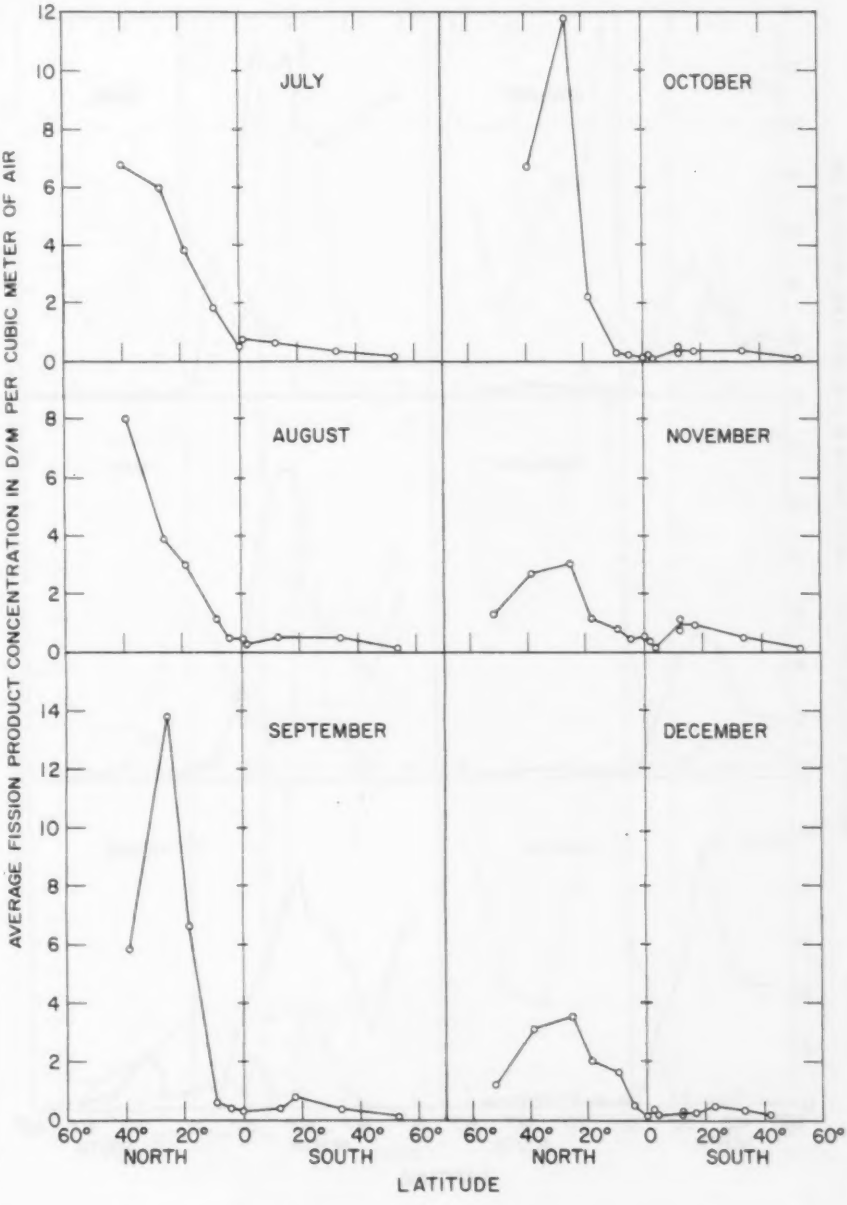

Fig. 2 - Radioactivity profiles - July through December 1957

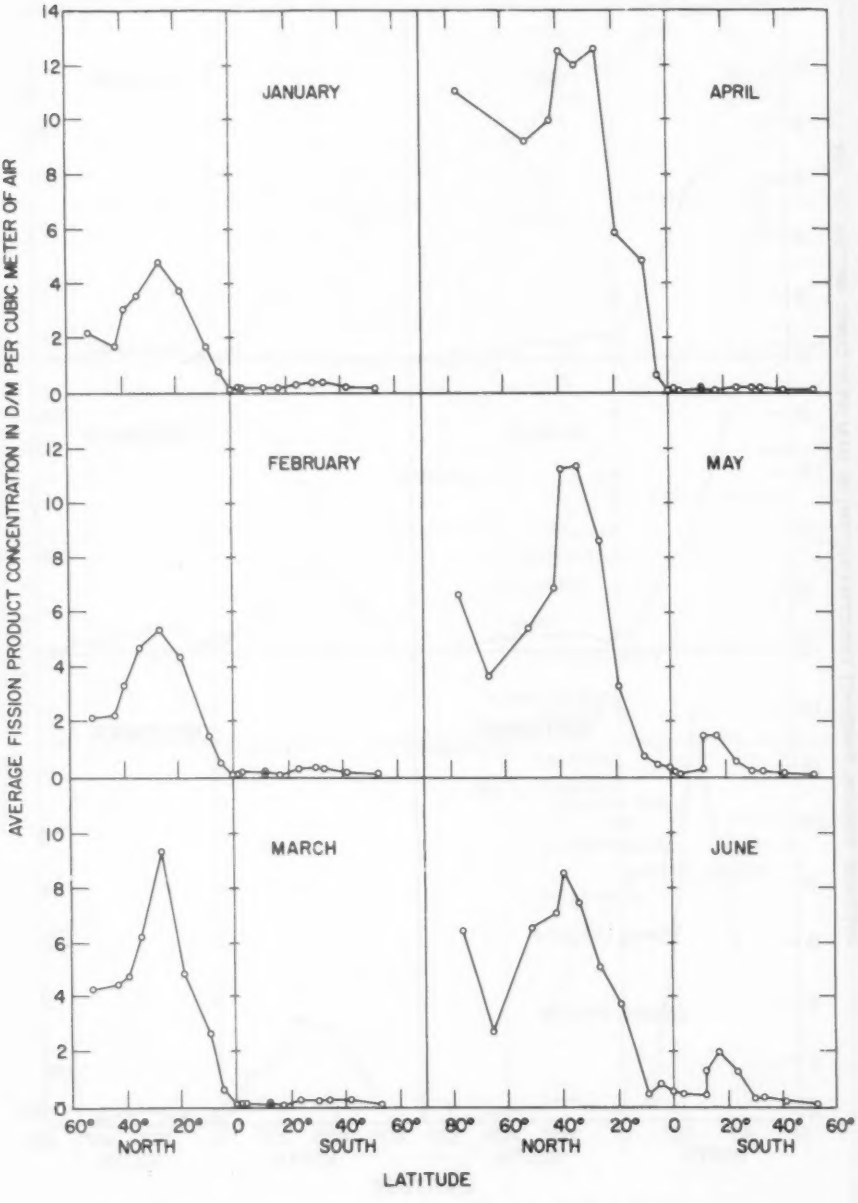

Fig. 3 - Radioactivity profiles - January through June 1958

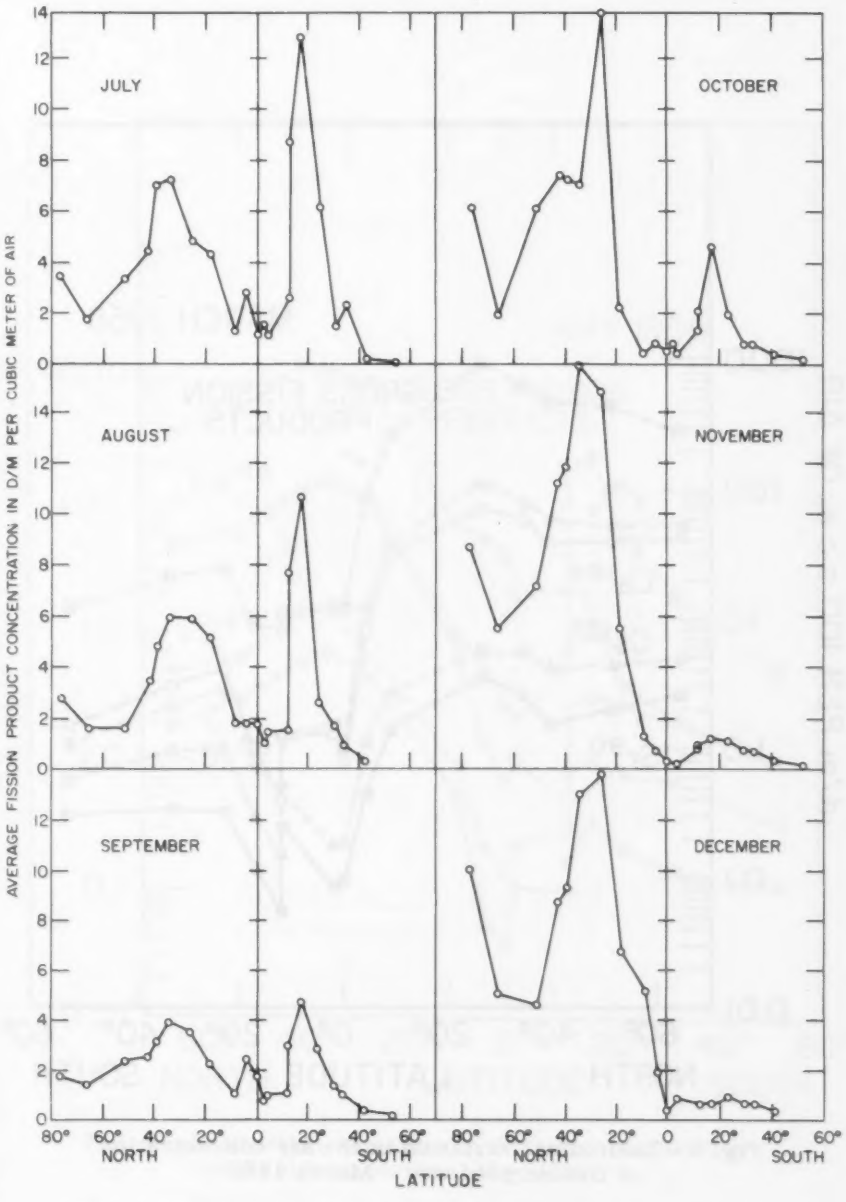

Fig. 4 - Radioactivity profile - July through December 1958

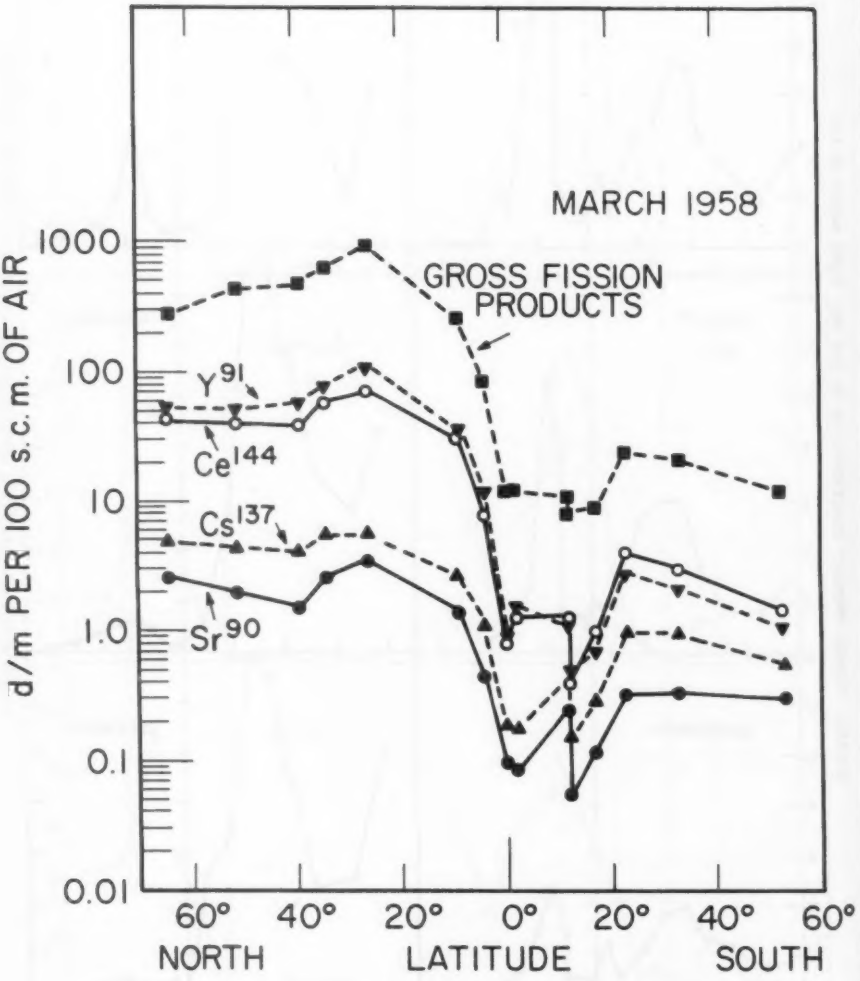

Fig. 5 - Latitudinal variation in the air concentration of fission products - March 1958

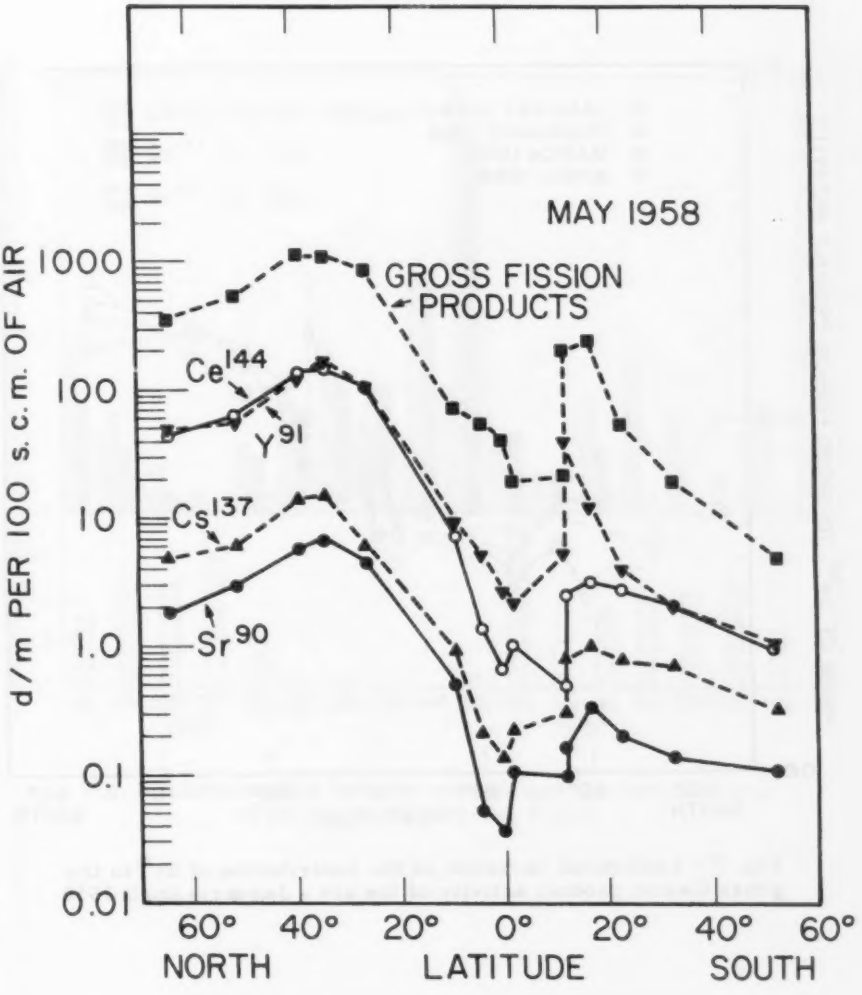

Fig. 6 - Latitudinal variation in the air concentration of fission products - May 1958

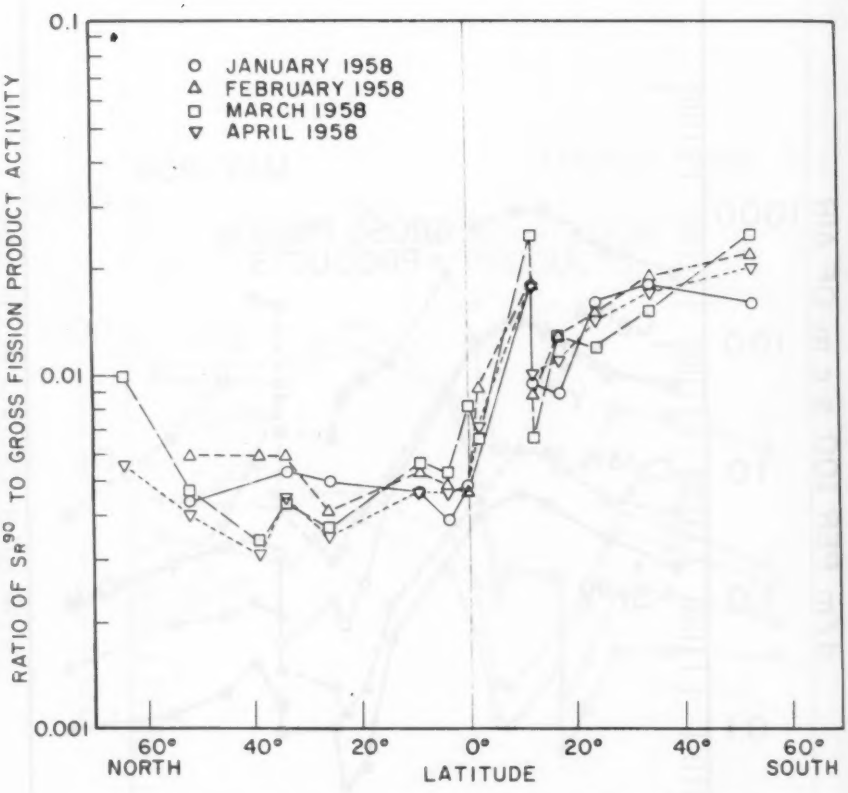

Fig. 7 - Latitudinal variation of the contribution of Sr^{90} to the gross fission product activity of the air - January-April 1958

RAINFALL (IN) ATMOSPHERIC RADIOACTIVITY (d/min/m³)

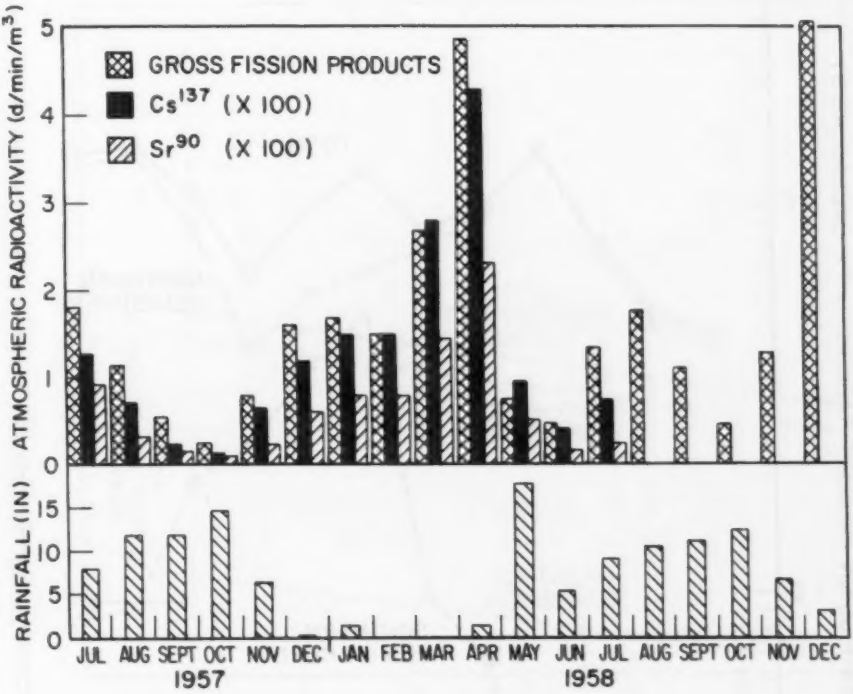
GROSS FISSION PRODUCTS
Cs137 (X 100)
Sr90 (X 100)
ATMOSPHERIC RADIOACTIVITY (d/min/m3)
RAINFALL (IN)
JUL AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEPT OCT NOV DEC
1957
1958

Fig. 8 - Relationship between rainfall and the radioactivity of the air at Miraflores, P.C.Z.

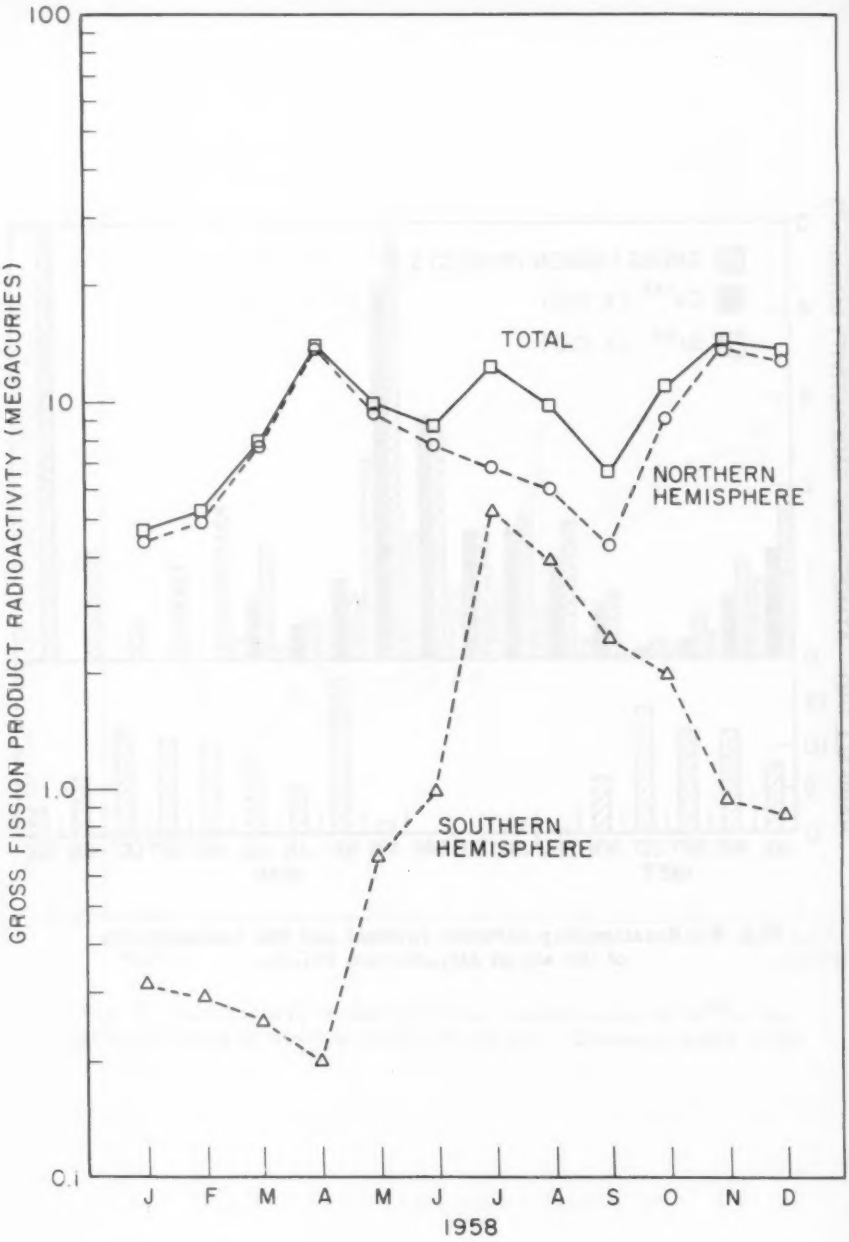

Fig. 9 - Gross fission product burdens in the troposphere

RELATIVE Sr^{90} BURDEN IN THE TROPOSPHERE

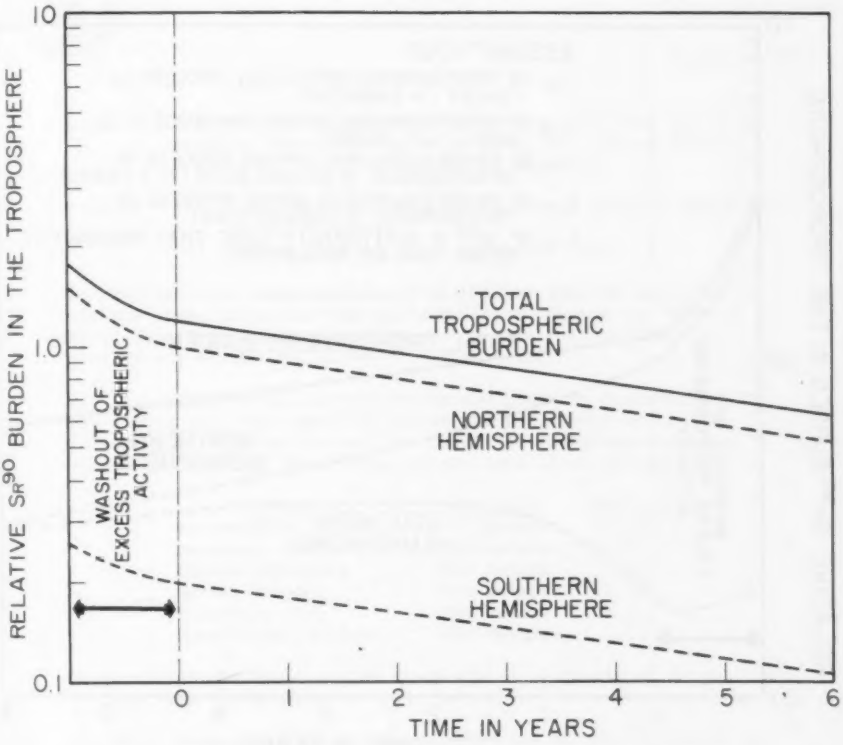

Fig. 10 - Postulated changes in tropospheric burdens of Sr^{90} assuming no stratospheric mixing across the Equator

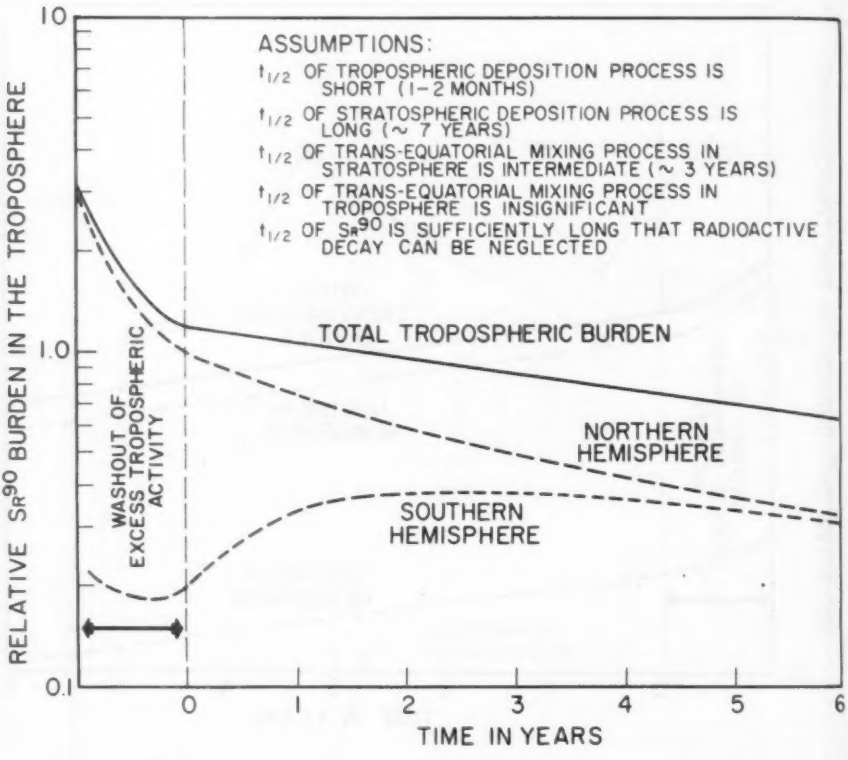

Fig. 11 - Postulated changes in tropospheric burdens of Sr^{90} assuming limited stratospheric mixing across the Equator

APPENDIX A

NRL ltr rpt 6110-121A:LBL:ee of 20 Apr 1959 entitled "Fission Product Radioactivity of the Air Along the 80th Meridian (West) during March 1959."

U. S. NAVAL RESEARCH LABORATORY
WASHINGTON 25, D. C.

IN REPLY REFER TO

6110-121A:LBL:ee

20 April 1959

Subj: Fission product radioactivity of the air along the 80th meridian (west) during March 1959; NRL Problem A02-13, Project No. NR 571-003; interim report on

Figure: (1) Daily Record of Fission Product β-Activity Collected by Air Filtration
(2) Radioactivity Profile for March 1959

1. Radioactivity measurements of air-filter samples collected at various sites along the 80th meridian (west) during the month of March 1959 are presented in Figure (1). The radioactivity profile for March 1959 is shown in Figure (2).

2. All radioactivity concentrations are given in disintegrations per minute per cubic meter of air at the collecting site. The following factors may be used to correct to disintegrations per minute per standard cubic meter of air (sea level density):

Station	Altitude	Factors
Antofagasta, Chile	519 meters	1.06
Santiago, Chile	520 meters	1.06
Bogota, Colombia	2640 meters	1.30
Quito, Ecuador	2818 meters	1.33
Huancayo, Peru	3353 meters	1.39
Chacaltaya, Bolivia	5220 meters	1.71

No correction is required for those stations located at an altitude of less than 300 meters.

3. These measurements are being carried out as part of the U. S. Naval Research Laboratory program of atmospheric radioactivity studies. Partial financial support is provided by the Division of Biology and Medicine, U. S. Atomic Energy Commission

L. B. Lockhart Jr.

L. B. LOCKHART, JR.

42165 O—59—vol. 1——33

FIGURE 1

DAILY RECORD OF FISSION PRODUCT β-ACTIVITY
COLLECTED BY AIR FILTRATION

March 1959

Day	Punta Arenas	Puerto Montt	Santiago	Porto Alegre	Antofagasta	Chacaltaya	Huancayo
	disintegrations/minute per cubic meter of air						
1	0.24	0.64	0.57	0.35	0.46	-	-
2	0.16	0.56	0.41	0.82	0.60	-	-
3	T	0.40	0.43	0.90	0.49	-	-
4	0.11	0.51	0.73	0.82	0.57	-	-
5	0.16	1.14	1.17	1.38	0.38	-	-
6	0.13	0.61	0.98	0.80	0.30	-	-
7	0.13	0.27	0.60	0.64	0.33	-	-
8	T	0.77	0.43	0.45	0.43	-	-
9	-	0.40	0.41	0.35	0.33	-	-
10	0.16	0.69	0.43	0.40	0.33	-	-
11	0.13	0.45	0.43	0.51	0.38	-	-
12	0.19	0.64	0.51	0.51	0.27	-	-
13	0.27	0.67	0.43	0.43	0.30	-	-
14	0.40	0.43	0.51	0.45	0.33	-	-
15	0.27	0.43	0.73	0.53	0.33	-	-
16	0.24	0.64	0.49	0.59	0.30	-	-
17	0.11	0.27	0.60	0.21	0.33	-	-
18	0.13	0.35	0.84	1.06	0.41	-	-
19	0.21	0.72	0.54	0.51.	0.46	-	-
20	0.59	0.64	0.43	-	0.46	-	-
21	0.21	0.51	0.41	0.27	0.49	0.12	-
22	0.11	0.32	0.30	-	0.49	0.26	-
23	0.16	0.48	0.16	-	0.41	0.24	-
24	0.13	0.40	0.27	-	0.35	0.26	-
25	T	0.64	0.22	-	0.46	0.24	-
26	-	0.21	0.3*	-	0.43	0.24	-
27	-	0.13	0.22	-	0.24	0.21	-
28	-	0.35	0.46	-	0.22	0.21	-
29	-	0.13	0.43	-	0.33	0.18	-
30	-	0.16	0.57	-	0.35	0.21	-
31	-	0.21	0.41	-	0.27	0.27	-
Mean value	0.18	0.48	0.50	0.60	0.38	0.22	-

* denotes combined collections
\- not received
T Trace

FIGURE 1 (Cont'd)

DAILY RECORD OF FISSION PRODUCT β-ACTIVITY
COLLECTED BY AIR FILTRATION

March 1959

Day	Lima	Iquitos	Guaya-quil	Quito	Bogota	Mira-flores	San Juan
	disintegrations/minute per cubic meter of air						
1	0.40	-	-	0.10	1.55	11.0	0.11
2	0.24	-	-	0.21	2.00	9.45	5.52
3	0.27	-	-	0.21	0.62	5.01	3.77
4	0.48	-	-	0.40	1.38	4.29	4.95
5	0.48	-	-	0.40	1.98	5.94	5.64
6	0.32	-	-	0.38	1.93	6.03	6.26
7	0.24	-	-	0.50	2.76	7.68	0.13
8	0.35	-	-	0.69	2.95	7.89	14.4
9	0.32	-	-	0.40	2.76	6.66	1.93
10	0.21	-	-	0.45	3.45	10.2	6.67
11	0.21	-	-	0.43	3.17	17.6	11.1
12	0.32	-	-	0.93	2.17	11.8	7.98
13	0.21	-	-	0.31	0.69	5.97	10.1
14	T	-	-	0.33	0.90	6.72	10.6
15	0.24	1.62	-	0.26	3.05	24.8	11.8
16	0.16	1.76	-	0.14	6.83	22.6	11.3
17	0.29	2.42	-	0.64	4.00	10.9	10.3
18	0.32	2.23	-	0.33	4.12	17.2	9.45
19	0.27	2.66	-	0.50	0.21	14.1	11.5
20	-	0.45	-	2.33	7.59	9.42	12.7
21	0.19	0.51	-	1.79	7.26	12.0*	17.0*
22	0.11	0.61	-	1.07	3.62	12.0*	17.0*
23	0.37	0.45	-	0.71	1.95	11.4*	16.8
24	0.27	0.45	-	0.29	1.52	11.4*	14.2
25	0.11	0.59	-	0.40	1.45	14.9	11.7
26	-	0.43	-	1.00	4.12	13.0	9.98
27	0.13	-	-	0.24	2.78	7.53	16.1
28	0.11	-	-	0.12	2.09	8.28	8.00
29	-	-	-	0.43	2.05	9.27	16.6
30	-	-	-	0.77	1.84	7.98	6.28
31	-	-	-	0.11	1.57	7.83	10.5
Mean value	0.26	1.18	-	0.54	2.72	10.67	9.69

* denotes combined collections
\- not received
T Trace

FIGURE 1 (Cont'd)

DAILY RECORD OF FISSION PRODUCT β-ACTIVITY
COLLECTED BY AIR FILTRATION

March 1959

Day	Miami	Columbia S.C.	Washington	Bedford	Moosonee	Coral Harbour	Thule
	disintegrations/minute per cubic meter of air						
1	11.2	32.6	16.9	17.3*	13.9	7.00	13.1
2	25.5	10.8	25.8	17.3*	9.38	7.50	11.6
3	28.4	16.1	16.7	9.75	14.0	10.1	14.7
4	36.2	14.0	14.2	9.89	7.31	5.13	17.2
5	45.7	15.6	14.2	3.13	11.2	5.75	12.7
6	5.43	11.5	9.68	6.14	8.56	2.71	13.5
7	17.5	17.0	18.1	6.67	8.17	9.87	17.2
8	22.2	22.7	11.3	11.6	7.08	12.8	23.5
9	33.3	18.9	12.2	21.4	6.83	6.90	26.8
10	23.8	20.0	15.1	17.1	6.92	9.09	23.4
11	37.9*	19.5	9.50	15.0	9.13	12.3	15.1
12	37.9*	21.9	10.9	16.2	10.6	10.3	14.2
13	20.1	9.48	11.2	7.20	10.2	9.13	13.2
14	21.4	17.5	9.20	16.6	11.1	7.50	11.1
15	43.0	22.3	13.2	5.41	8.28	13.5	9.61
16	32.1	23.1	16.8	7.41	13.2	12.7	9.50
17	15.6	19.1	11.0	11.5	6.76	8.76	10.6
18	13.0	21.9	10.6	11.2	11.3	10.2	8.05
19	19.4	23.2	11.8	17.0	9.98	11.5	8.63
20	12.5	13.9	14.6	13.8	9.02	12.1	13.9
21	8.10	9.34	15.9	17.1	14.9	16.5	13.7*
22	14.5	12.4	16.0	13.0	14.4	12.9	13.7*
23	17.0	39.1*	14.4	11.8	11.2	11.6	11.5
24	26.5	39.1*	21.8	22.9	7.64	12.3	10.4
25	34.8	26.1*	29.2	16.3	12.1	11.9	11.6
26	27.3	26.1*	23.0	19.8	12.2	-	12.3
27	25.7	19.8	14.9	17.3	9.22	-	13.8
28	27.7	12.9	6.44	12.8	9.34	-	13.1
29	24.0	23.1	24.7	18.6	18.5	-	14.6
30	16.6	13.8	21.6	21.4	19.7	-	14.0
31	28.4	3.11	9.02	21.0	7.27	-	9.20
Mean value	24.3	19.2	15.2	14.0	10.5	10.0	13.7

* denotes combined collections
\- not received
T Trace

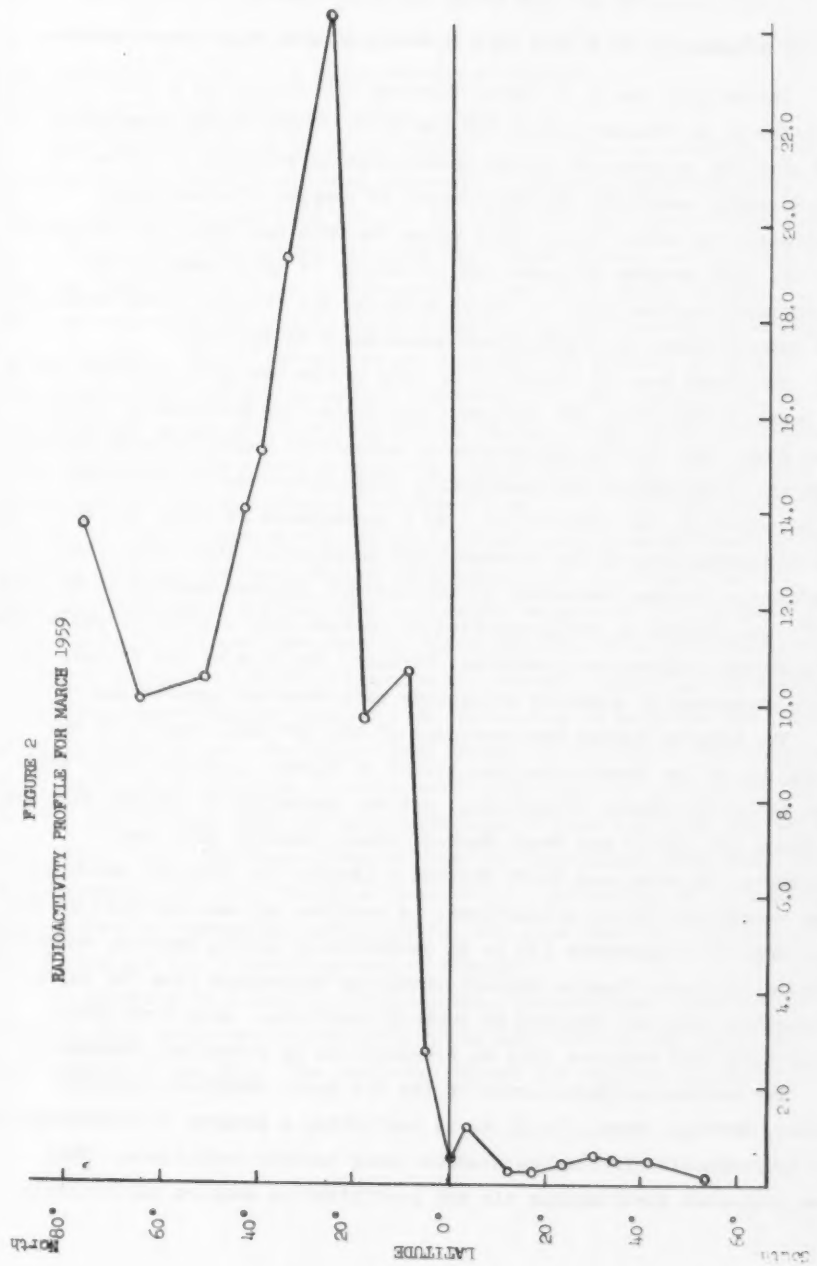

FIGURE 2
RADIOACTIVITY PROFILE FOR MARCH 1959

PROGRAM OF MEASUREMENT OF THE RADIOACTIVITY OF THE AIR ALONG THE 80TH MERIDIAN

L. B. Lockhart, Jr., R. A. Baus, and I. H. Blifford, Jr., of the Naval Research Laboratory

During 1956 the U. S. Naval Research Laboratory, in a joint program with the U. S. Weather Bureau and the U. S. Atomic Energy Commission and with the cooperation of the meteorological services of Chile, Peru and Ecuador, undertook the measurement of samples of atmospheric radioactivity collected at sites along the 80th meridian. As initially set up, this program included the collection of daily samples of atmospheric radioactivity by three methods: air filters, cloth screens and gummed films, with subsequent measurement at NRL (1).

The first year of operation of this system has given indications as to means of improving the equipment and collecting procedures. It has been found that little information of scientific value is being obtained from the cloth-screen and gummed-film collections due to the difficulty of interpreting the results (2). As a consequence of this, and following the recommendation of the International Geophysical Year (IGY) Panel on Atmospheric Nuclear Radiation at the Utrecht, Holland meeting in February 1957, the program is being modified to include only air-filter collections of airborne radioactive products. Further, the size of the filters is being decreased to simplify subsequent radiochemical separations.

The program during the remainder of the IGY will consist of the operation of the twenty stations listed in Figure 1, all of which will make daily air-filter collections, and the operation of similar stations at Mauna Loa (Hilo) and Pearl Harbor (Oahu), Hawaii; Subic Bay, Philippine Islands; and Drift Station A (Arctic ice island), which will make weekly air filter collections. A complete air monitor unit of the type described elsewhere (3) is in operation at Little America, Antarctica. Data on the gross fission product levels as determined from the daily collections will be reported at monthly intervals. Data from other collections and analyses will be presented on an irregular schedule.

The Geophysics Directorate of the Air Force Cambridge Research Center, Bedford, Mass., U. S. A. is initiating a program of stratospheric and tropospheric circulation studies using nuclear techniques. They have requested simultaneous air and precipitation samples particularly

from the rainy areas of the Southern Hemisphere and have suggested Thule, Bedford, Puerto Rico, Iquitos, Porto Alegre and Puerto Montt as possible locations. They plan to analyze air filter and precipitation samples for Sr^{90}, Cs^{137}, tritium and other isotopes.

Measurement of Gross Fission Product Levels

Each station making daily air-filter collections is equipped with a positive-displacement air pump driven by a constant speed electric motor. The initial air flow rate is 40 cubic feet per minute when the large filter (17 x 13 inches) is used (30 cfm at Panama) and 30 cfm when the small filter (8-inch diameter) is used (23 cfm at Panama). The flow rate does not change appreciably during the 24-hour operation of the blower. The filter papers are changed each morning at 0730-0800 local time, and are forwarded immediately to NRL, Washington, D. C. Here they are ashed at 650°C in a muffle furnace, compressed to a thin wafer in a hydraulic press, mounted on plastic dishes and assayed for β-activity using a thin-window, halogen-filled G. M. tube and conventional circuitry. The equipment has been calibrated using standardized radio-isotopes from the National Bureau of Standards, U. S. Department of Commerce, which were mounted with equivalent weights of filter ash. All counting rates are converted to disintegration rates by assuming an average β-energy of 1 MeV for the fission products and using the appropriate efficiency factor for the counter. No correction is made for the loss of volatile products upon ignition. Each sample is counted on the 14th day after collection, in order to allow sufficient time for receipt of the samples and for the decay of the short-lived fission products and natural radioactivities. The long-lived RaD and its descendents have been found to contribute little to the gross β-activity. Activities of individual filters having measurable radioactivity, but less than 0.07 d/m per m^3 (0.002 d/m per $ft.^3$) are tabulated as traces.

In Figure 2 is a listing of the gross fission product activities obtained from daily air filter collections made during July 1957, the first month of the IGY. The tabulated values for samples collected over

periods longer than 24 hours represent the total measured activity divided by the number of 24-hour periods in the collection.

An example of the use to which such measurements may be put is shown in Figure 3, where the average concentration of fission product radioactivity in the air during the week of July 21-27, 1957 is plotted against the latitude of the collecting station. This "radioactivity profile" points out the unsymmetrical distribution of fission products in the atmosphere at the present time.

Determination of the Long-Lived Radioactive Constituents of the Atmosphere

It is planned to analyze as many samples as possible for the following radioisotopes: Sr^{89}, Sr^{90}, Y^{91}, Cs^{137}, Ce^{141}, Ce^{144} and Pb^{210} (RaD). Each sample will consist of a month's collection of air filter samples from a given station. An important factor in the decision to reduce the size of the filter paper used was the resulting simplification of the radiochemical techniques for separation of these isotopes. Radiochemical procedures have been developed which enable satisfactory yields of each of these elements to be obtained in a sequential analysis from the ash of 30 filter papers (8"-diameter). Some additional samples will be made available to the Geophysics Research Directorate, Air Force Cambridge Research Center for analysis in their program of evaluation of the radioactivity in the atmosphere and in precipitation. The results will be made available to the participants in this program.

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FIGURE 1

SITES OF DAILY COLLECTIONS OF ATMOSPHERIC RADIOACTIVITY DURING THE IGY

STATION	APPROX. LOCATION LAT.	LONG.	COOPERATING ACTIVITY	INITIAL OPERATION OF AIR FILTER
Thule, Greenland	76°30'N	68°W	U. S. Air Force	September 1957 *
Coral Harbour, NWT	66°N	84°W	Canadian Meteorological Service	September 1957 *
Moosonee, Ont.	51°30'N	81°W	Canadian Meteorological Service	September 1957 *
Bedford, Mass.	42°20'N	71°30'W	U. S. Air Force	October 1957 *
Silver Hill, Md.	39°N	77°W	U. S. Weather Bureau	May 1956 **
Miami, Fla.	25°40'N	80°20'W	U. S. Weather Bureau	June 1957
San Juan, P. R.	18°40'N	66°W	U. S. Weather Bureau	June 1957
Miraflores P. C. Z.	9°N	79°30'W	U. S. Naval Research Laboratory	June 1956
Bogota, Colombia	4°37'N	74°04'W	Instituto Geofisico de los Andes Colombianos	July 1957
Quito, Ecuador	15'S	78°30'W	National Committee of the IGY	March 1957
Guayaquil, Ecuador	2°15'S	80°W	National Committee of the IGY	May 1956
Iquitos, Peru	3°40'S	73°20'W	Meteorologia del Peru	September 1957 *
Lima, Peru	12°S	77°W	Meteorologia del Peru	October 1956
Huancayo, Peru	12°S	75°W	Meteorologia del Peru	September 1957 *
Chacaltaya, Bolivia	17°S	68°W	Universidad Mayor de San Andres	September 1957 *
Antofagasta, Chile	23°40'S	70°30'W	U. S. Naval Research Laboratory/IGY	September 1957 *
Porto Alegre, Brazil	30°S	51°W	* * *	* * *
Santiago, Chile	33°30'S	70°40'W	Servicio Nacional de Meteorologia	November 1956
Puerto Montt, Chile	41°40'S	73°W	* * *	* * *
Punta Arenas, Chile	53°S	71°W	Servicio Nacional de Meteorologia	May 1957

* Estimated starting date

** Equipment operated at NRL, Washington, D. C., May 1956-June 1957

*** Tentative

FIGURE 2

DAILY RECORD OF FISSION PRODUCT β-ACTIVITY
COLLECTED BY AIR FILTRATION

July 1957

Day	Punta Arenas	Santiago	Lima	Guayaquil	Quito
			$d/m/m^3$		
1	T	0.10	1.53	-	0.10
2	0.10	0.10	0.73	-	0.12
3	0.14	0.42	-	-	T
4	T	0.31	0.37	-	0.14
5	T	0.84	0.33	-	0.16
6	T	0.73	0.31	-	0.61
7	0.10	T	0.20	-	1.67
8	T	0.12	0.51	-	T
9	T	0.10	0.57	1.53	0.10
10	T	0.40	0.51	1.57	0.63
11	T	0.14	0.45	0.67	0.34
12	0	T	0.43	0.82	0.10
13	T	T	0.33	-	0.53
14	T	T	0.33	0.27	0.92
15	T	0.27	0.20	0.44	0.27
16	T	0.55	0.20	-	0.35
17	0	0.98	0.31	1.16	0.16
18	T	0.16	0.27	0.37	0.37
19	T	0.40	0.31	-	0.37
20	T	0.40	0.53	0.71	T
21	T	0.27	0.78	0.78 *	0.53
22	0.20	0.37	1.24	0.78 *	0.83
23	0.16	0.31	0.41	0.27	1.16
24	0.14	0.45	1.02	-	1.43
25	-	0.37	1.57	-	0.61
26	0.10	0.61	0.96	0.80 *	0.20
27	T	0.41	0.98	0.80 *	0.47
28	0.20	T	1.43	-	0.31
29	0.16	0.53	1.04	0.62 *	0.43
30	T	T	0.41	0.62 *	-
31	0.14	0.20	0.51	1.16	0.35

* combined collections T trace

FIGURE 2 (con't)

DAILY RECORD OF FISSION PRODUCT β-ACTIVITY
COLLECTED BY AIR FILTRATION

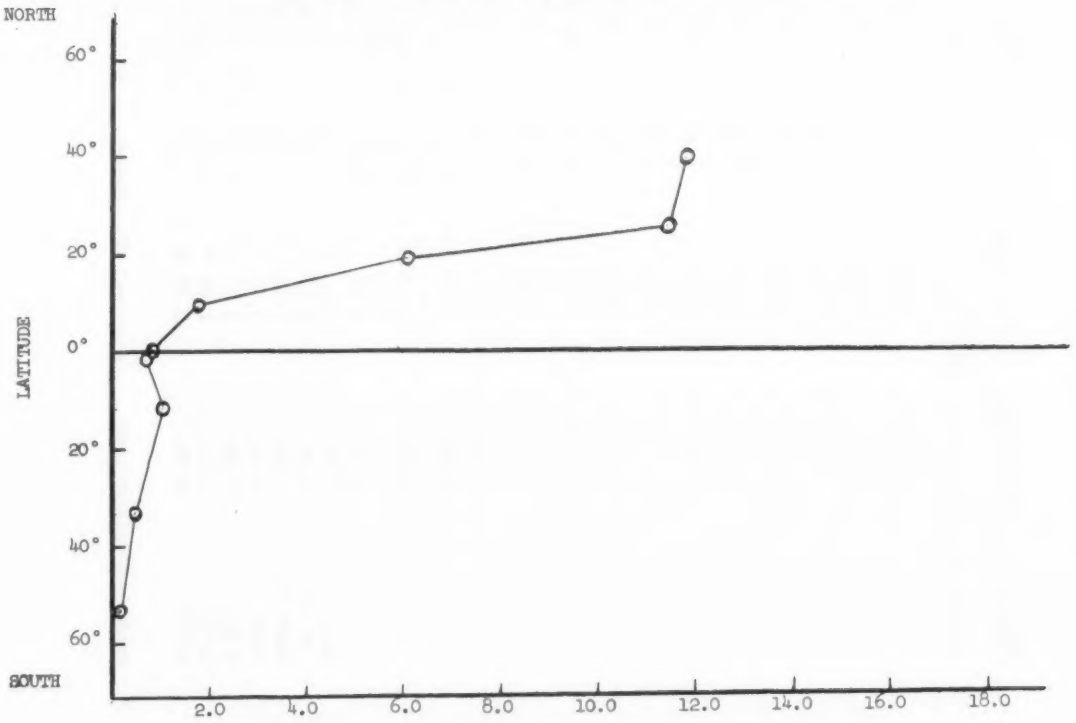
July 1957

Day	Bogota	Miraflores	San Juan	Miami	Washington
		d/m/m^3			
1		0.54	1.65	3.94	2.95
2		0.72	1.83	3.04	1.02
3		1.86	6.84	2.81	2.77
4		1.17	1.88	6.21	3.63
5		1.51	1.66	4.60	4.39
6		1.19	5.45	3.76	7.37
7		2.84	3.85	3.67	4.28
8		1.74 *	2.36	2.90	2.83
9		1.74 *	3.35	2.65	3.94
10		7.03	1.04	3.13	10.5
11		1.15	2.44	3.33	2.03
12		-	2.92	4.07	2.63
13		0.77	2.92	5.55	3.66
14		0.63	3.26	5.37	0.63
15		2.46 *	4.37	4.37	19.2
16		2.46 *	4.51	4.51	5.29
17		1.83	2.96	2.96	2.33
18		1.54	4.00	5.00	2.07
19		4.43	5.22	4.60	2.44
20		1.06	7.10	11.7	3.22
21		1.64	-	13.6	4.29
22		1.06	5.48	17.5	36.9
23		4.43	7.59	11.6	28.7
24		1.74	5.74	10.8	5.48
25	0.15	0.82	7.10	9.36	1.96
26	T	1.78	9.18	8.66	2.89
27	0.00	0.53	1.22	8.10	2.04
28	0.00	0.92	3.33	4.10	3.07
29	0.81	0.96	2.11	4.80	5.59
30	1.78	1.01	1.79 *	2.85	12.7
31	2.81	2.36	1.79 *	4.00	18.0

* combined collections T trace

FIGURE 3

RADIOACTIVITY PROFILE FOR WEEK OF JULY 21-27, 1957



FISSION PRODUCT RADIOACTIVITY IN THE AIR ALONG THE 80th MERIDIAN - January - June 1957

L. B. Lockhart, Jr., R. A. Baus, and I. H. Blifford, Jr.,* of the Naval Research Laboratory

INTRODUCTION

The program of measurement of fission product radioactivity in the air along the 80th meridian (west), initiated in early 1956, has been continued and expanded during 1957.

Collections of radioactivity have been made by (a) air filters employing a positive displacement pump with a free-air capacity of about 40 cfm and an efficient filter paper, (b) cloth screens (cheesecloth) of one square foot area mounted in a vertical position and held normal to the air stream by a vane, and (c) the standard AEC gummed-film collector for fallout particles. Comparisons of such collections (1) have indicated the latter two devices to be unsuitable due to the difficulty of interpreting the results. Further, the extremely low levels of activity obtained by the latter two devices, even when significant amounts of radioactivity were being collected by the air-filter method, make inconclusive any comparisons made on such days.

During the International Geophysical Year, the major effort will be placed on the collection of radioactivity by the air-filter method, with subsequent measurement at NRL. The elimination of the gummed-film and cloth-screen collections will enable the NRL counting facilities to be employed to give coverage of more geographical locations along the 80th meridian.

This report covers a final comparison of the three collecting methods and traces the changes in the gross fission product radioactivity of the air that have occurred during the period January - June 1957.

COLLECTION AND MEASUREMENT OF SAMPLES

Samples of atmospheric radioactivity were collected at the various cooperating collecting sites and forwarded to the U. S. Naval Research Laboratory via air mail. Here the samples were ignited to an ash at 650°C and measured for gross β activity two weeks after collection, as described previously (1). At the time of measurement, the natural radioactive materials in the air had decayed to insignificance.

RESULTS

Comparison of Collecting Techniques

In Fig. 1, a comparison of the weekly totals of the radioactivity of samples collected by the three techniques is presented for the four sites where relatively complete sets of

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AVERAGE FISSION PRODUCT CONCENTRATION IN D/M PER CUBIC METER OF AIR

such data are available: Santiago, Chile; Guayaquil, Ecuador; Miraflores, Panama Canal Zone; and Washington, D. C. All weekly totals of 100 disintegrations per minute or less have been omitted because of the lack of significance of such data.

At Santiago (Fig. 1a) the radioactivity collected by the air filters showed a downward trend from January through May, then increased sharply in June following the British atomic tests at Christmas Island. The cloth-screen collections gave no siginificant indications of activity except for June 11-17, which corresponded to a minimum in the concentration of fission product radioactivity in the air. The gummed-film collections, too, were generally low in radioactivity and showed no correlation with the air-filter collections.

At Guayaquil (Fig. 1b) the radioactivity of the air-filter collections showed the same downward trend as at Santiago. The cloth-screen collections were of no value because of their low activity. The gummed-film collections were generally of little significance except during May and June. These collections showed a rise in radioactivity prior to the British tests; however, the time of maximum activity of the gummed films did correspond roughly to that of the highest air concentrations shown by the filter collections.

At Panama (Fig. 1c) the fission product radioactivity of the air was generally high from January through April, then decreased markedly in May following the onset of the rainy season. The strong relationship between the air concentration of fission products and the rainfall, as described later, makes it difficult to assign rises in the activity level to any particular atomic test during the rainy season. Both the cloth-screen and gummed-film collections showed extreme variations in radioactivity which seldom coincided with variations in the radioactivity of the air.

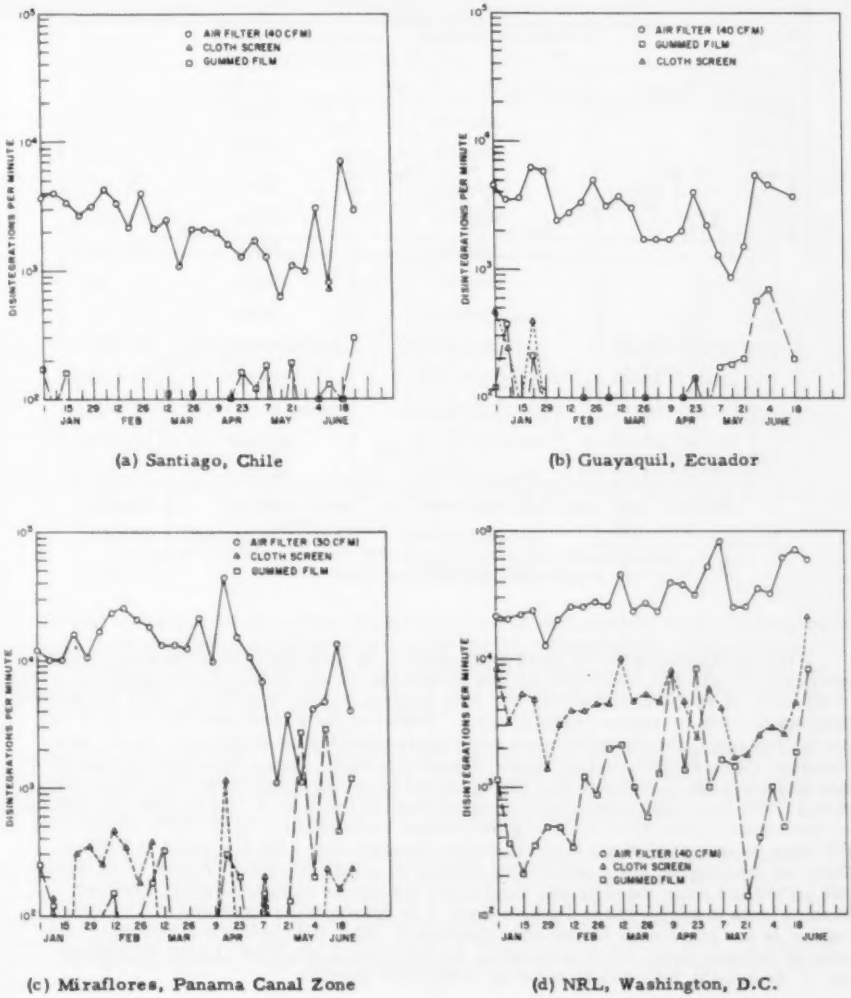
At Washington, D. C. (Fig. 1d) the radioactivity of the air-filter collections showed a general increase from January through June. In general, also, the cloth-screen collections gave parallel indications of radioactivity, but the quantity collected was much lower. The gummed-film collections showed considerably less correlation with the other collecting methods.

To generalize, the cloth-screen and gummed-film collections of radioactivity have no simple relationship to the actual air concentration of fission products. If, in the future, some presently unrecognized factors can be taken into account which seem to explain these present inconsistencies, the data accumulated during the past year will serve as a testing area. At the present time, however, it is evident that further collections by cloth screen or gummed films would serve no useful purpose, except where no other collecting technique is available.

Effect of Rainfall on the Radioactivity of the Air

Many measurements have shown that radioactive materials are swept from the air by rain with a resulting decrease in the radioactivity of the air. Previous work at NRL has shown rainfall to be the agent principally responsible for removal of natural radioactive products from the atmosphere in the Washington, D. C., area (2).

The data collected by the air-filter method at Panama on the fission product radioactivity of the air during the dry and rainy seasons (Fig. 2) gives a clear picture of the inverse relation between rainfall and atmospheric radioactivity. During the wet period from June through November 1956, the fission product radioactivity of the air was rather low in spite of a large number of atomic tests taking place in the Northern Hemisphere. The few peaks of activity coincided both with periods of less than normal rainfall and with periods of intensive atomic testing. It is remarkable that such a low response to the U.S. tests held in the Pacific during May-July 1956, was obtained, particularly since the prevailing high altitude winds from the test area normally pass near Panama.



(a) Santiago, Chile

(b) Guayaquil, Ecuador

(c) Miraflores, Panama Canal Zone

(d) NRL, Washington, D.C.

Fig. 1 - Weekly collections of radioactivity during January-June 1957
The dates along the abscissas are the initial days of the weekly collections

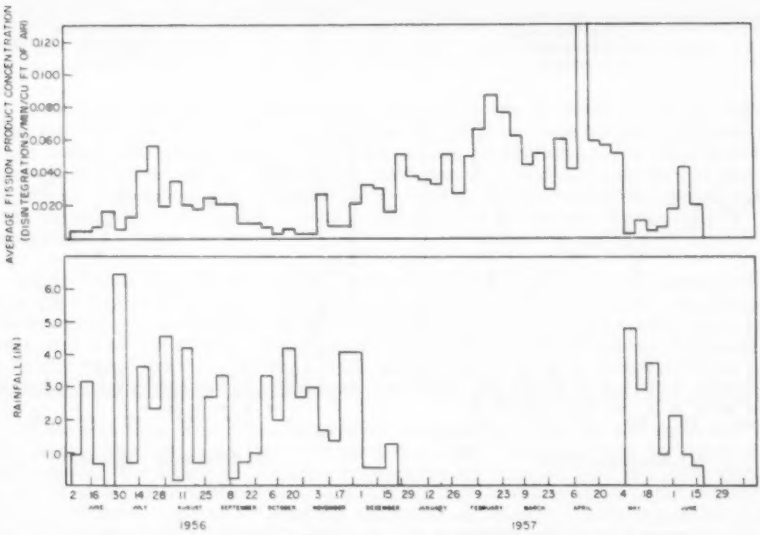


Fig. 2 - Relationship between rainfall and the radioactivity of the air at Miraflores, Panama Canal Zone

With the slackening of the rains in December, an immediate increase in the radioactivity of the air was observed. At this season the intertropical convergence zone moves to the south of Panama, permitting this area to receive ground-level air from the Northern Hemisphere with its higher radioactivity. Following the cessation of the rains at the end of December, the fission product count approached that at Washington, D. C., and remained high until the start of the rainy season in May. During this entire period there was only one peak of radioactivity that appeared to be due to any particular atomic test series. The maximum radioactivity measurement of the year at this location was obtained for the week of April 13-19 following the Russian tests of early April 1957. These tests and other nuclear explosions reported during January-June 1957 are listed in Table 1. Since the Washington, D.C. collections showed no great increase in radioactivity during this period and since the time was insufficient for debris from any but the first two Russian tests to arrive in the Panama area, it is reasonable to consider that this high reading is due principally to the accumulation of older debris in the atmosphere, possibly by diffusion from the stratosphere. Radiochemical analyses of such collections during the coming year should serve to clarify this question.

Radioactivity Profiles Along the 80th Meridian

Comparisons of the average air concentrations of fission products at the various collecting sites along the 80th meridian for the same periods of time are shown in Figs. 3 and 4. In Fig. 3, these "radioactivity profiles" are based on monthly air concentrations of fission products. During January through May the monthly profiles were generally representative of the individual weekly profiles. Following the increased nuclear test explosions in May and June both in the United States (Nevada) and at Christmas Island, large fluctuations in the activity levels occurred at most collecting sites. The radioactivity profiles during June are, therefore, presented also as weekly averages (Fig. 4).

TABLE 1
Date and Location of Nuclear Explosions
Recorded During January-June 1957

Date	Location	Government Responsible	Type of Test
Jan 19	USSR	Russia	
Mar 8	USSR	Russia	
Apr 3	USSR	Russia	
Apr 6	USSR	Russia	
Apr 10	USSR	Russia	
Apr 12	USSR	Russia	
Apr 16	USSR	Russia	
May 16	Christmas Island	United Kingdom	Fusion (megaton)
May 28	Nevada	United States	Small fission
May 31	Christmas Island	United Kingdom	Fusion (megaton)
June 2	Nevada	United States	Small fission
June 5	Nevada	United States	Small fission
June 19	Nevada	United States	Small fission
June 19	Christmas Island	United Kingdom	Fusion (megaton)
June 24	Nevada	United States	Small fission

During the period January-May, the general level of radioactivity in the air decreased in the Southern Hemisphere and increased in the Northern Hemisphere. The activity level at Panama was variable depending on the rainfall as discussed in a previous section. In general the fission product radioactivity of the air is higher by a factor of 5 or more in the Northern Hemisphere throughout this period.

A great increase in the fission product level in the air in both hemispheres during June 1957 is apparent from the weekly June profiles. The increases taking place south of Panama are due to the Christmas Island tests; those north of Panama are due primarily to the Nevada tests; those at Panama are presumably due to both test series.

The low levels of activity encountered near the Equator during June were unexpected in view of the nuclear explosions of several megatons yield having taken place previously at Christmas Island (2°N, 157°W). It will be most interesting in the future to see if this position of minimum activity changes seasonally, what is its relationship to the intertropical convergence zone, and perhaps whether a band of heavy rainfall near the Equator serves to bar passage from one hemisphere to the other of activity contained in the lower atmosphere.

When more complete coverage of the 80th meridian is obtained, integration of the area to the left of the profile curves will give useful information on the burden of radioactivity in the atmosphere at different times. In the absence of fresh debris and the resulting nonuniform distribution of this radioactivity, such calculations should prove useful for estimating worldwide fallout rates. The results of radiochemical analyses for specific isotopes such as Cs^{137} and Sr^{90} can be presented in a similar form and may be useful for determining fallout rates or accretion rates of these isotopes in the lower atmosphere.

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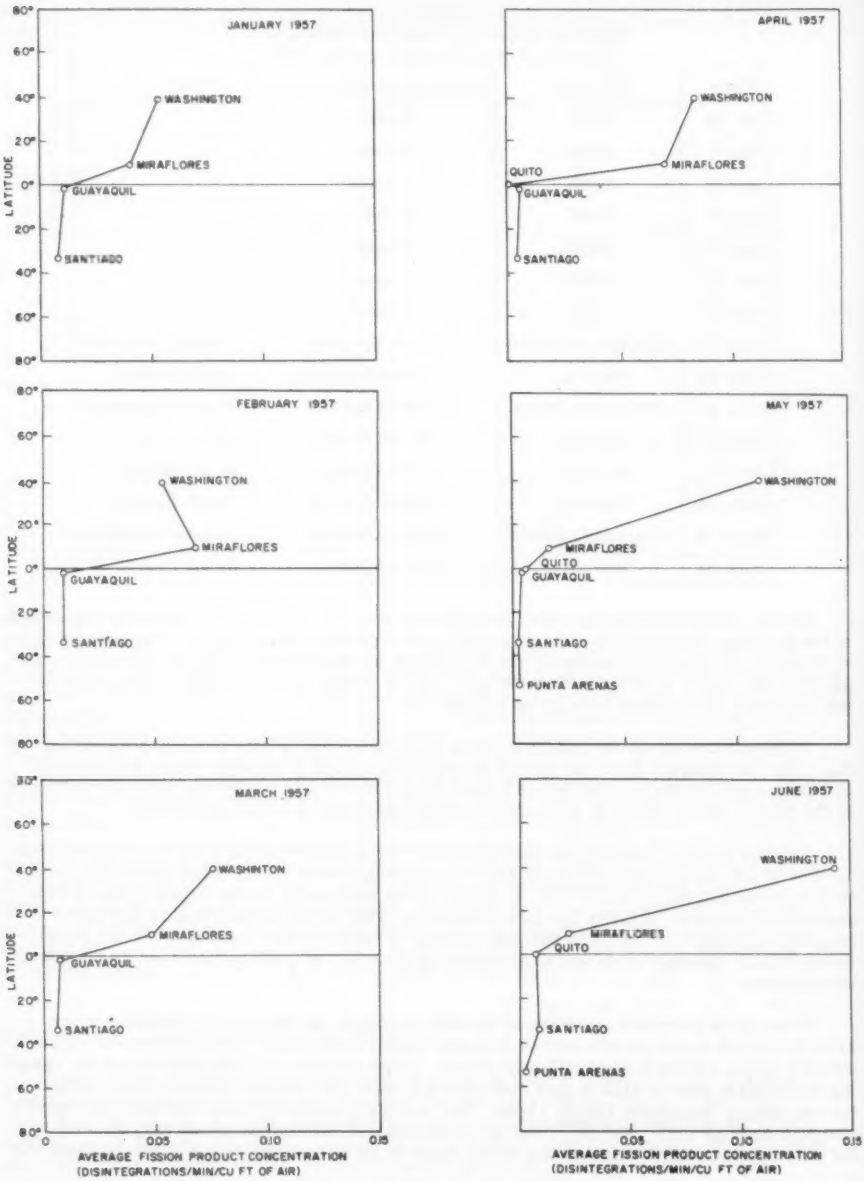

Fig. 3 - Radioactivity profiles of the air along the 80th meridian during January-June 1957

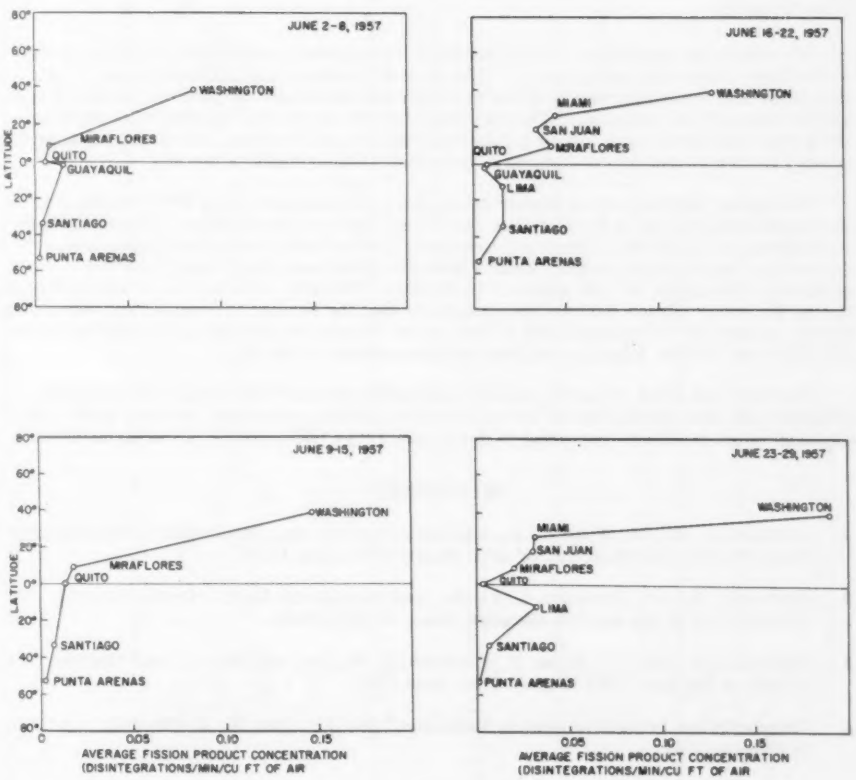

Fig. 4 - Radioactivity profiles of the air along the 80th meridian during June 1957

In Table 2, the maxima readings of the concentration of fission products in the air for each month and the monthly averages for each collecting station are compared in terms of curies per cc of air. The average fission product activity of the air at Washington during this period is about ten times that recorded on monitor equipment at NRL in early 1954 (3) during a period of relative quiet. The highest activity recorded at NRL this year (4.0×10^{-18} curies per cc) may be compared with the maximum of 6.1×10^{-17} curies per cc of air recorded here in May 1953 following a test in Nevada. The maximum activity recorded at any location in the Southern Hemisphere this year (2.2×10^{-18} curies per cc of air at Lima, Peru, June 1957) is far below the U.S. Atomic Energy Commission tolerance of 1×10^{-15} curies per cc of air for continuous exposure to unidentified β emitters (4).

CONCLUSIONS

In view of the inadequacy of correlations of radioactivity measurements made by use of the three collecting techniques (air filters, cloth screens, and gummed films), it is concluded that for the present only the air-filter method should be used for routine atmospheric radioactivity sampling. The air-filter method can be used to determine directly the gross concentration of fission products in the air, and, further, radiochemical analysis of the filters can give concentrations of individual radioisotopes in the air.

The gross radioactivity of the air during the period January-June 1957 continues to be considerably higher in the Northern than in the Southern Hemisphere. There has been no evidence yet found that indicates transport of radioactivity in the lower atmosphere across the "equatorial barrier." Debris from the Christmas Island test, however, apparently did appear on both sides of the Equator. The low radioactivity levels in Panama during the rainy season indicate the possibility that the barrier to transport of debris may be due, in part, to a continuous belt of rain in the tropics which effectually removes radioactivity from air that might cross from one hemisphere to the other.

As more and more collecting stations are added to this 80th meridian air sampling program, the data obtained gives every indication of being extremely valuable in estimating long-range processes operating to modify the gross radioactivity of the atmosphere.

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TABLE 2

Monthly Averages and Maxima of Fission Product Radioactivity During January–June 1957

Location	Radioactivity (curies/cc of air)											
	January		February		March		April		May		June	
	Monthly Average	Maximum*	Monthly Average	Maximum	Monthly Average	Maximum	Monthly Average	Maximum	Monthly Average	Maximum	Monthly Average	Maximum
Washington	8.4×10^{-16}	1.2×10^{-15} (26–28)†	8.6×10^{-16}	1.8×10^{-15} (20)	1.2×10^{-15}	3.0×10^{-15} (15)	1.3×10^{-15}	2.5×10^{-15} (19)	1.8×10^{-15}	4.0×10^{-15} (9)	2.2×10^{-15}	7.4×10^{-15} (27)
Miami‡											6.4×10^{-16}	1.5×10^{-15} (17)
San Juan‡											5.1×10^{-16}	1.6×10^{-15} (20)
Miraflores	6.4×10^{-16}	1.5×10^{-15} (24)	1.1×10^{-15}	1.9×10^{-15} (18)	7.8×10^{-16}	1.4×10^{-15} (10)	1.4×10^{-15}	3.8×10^{-15} (18)	2.5×10^{-15}	8.9×10^{-15} (6)	3.3×10^{-15}	3.7×10^{-15} (18)
Quito							1.6×10^{-20}	9.6×10^{-20} (6)	9.6×10^{-20}	9.2×10^{-15} (27)	1.1×10^{-15}	6.4×10^{-15} (12)
Guayaquil§	1.8×10^{-15}	3.5×10^{-15} (26)	1.4×10^{-15}	4.5×10^{-15} (2)	1.1×10^{-15}	2.9×10^{-15} (4)	8.5×10^{-20}	5.1×10^{-15} (26)	6.4×10^{-20}	2.1×10^{-15} (30,31)	1.8×10^{-15}	6.0×10^{-15} (3)
Lima‡											3.3×10^{-15}	2.2×10^{-15} (25)
Santiago	1.3×10^{-15}	2.2×10^{-15} (10)	1.4×10^{-15}	3.8×10^{-15} (5)	8.0×10^{-20}	2.1×10^{-15} (1)	6.4×10^{-20}	1.1×10^{-15} (2,11)	3.2×10^{-20}	9.5×10^{-20} (1,2,8,26)	1.3×10^{-15}	7.2×10^{-15} (19)
Punta Arenas									4.8×10^{-20}	1.3×10^{-15} (21)	3.2×10^{-20}	1.6×10^{-15} (1,22)

* * *

*The day (or days) on which the maximum occurred is given in parentheses below the value

†Average for a 3-day collection

‡Data available June 14–30 at Miami and San Juan, June 13–30 at Lima

§No data available June 25–30

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SOME MEASUREMENTS OF THE RADIOACTIVITY OF THE AIR DURING 1957

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INTRODUCTION

The radioactivity of the air was a subject of much interest during the years following the discovery of the phenomenon of radioactive decay. After the passing of the initial enthusiasm for such studies relatively few measurements were made until the advent of the nuclear age and the resulting introduction of new radioactive materials into the atmosphere.

Currently, the levels of the various radioactive components of the atmosphere are again of great interest because of their unknown effect on man and his environment.* This report deals with the measurement of the concentrations of various radioactive materials in the air; it does not attempt to evaluate the biological hazard to man from the addition of this new factor in his environment.

The radioactivity of the air is due to a great number of radioactive species besides the radioactive materials introduced by man. Small quantities of uranium, thorium, and potassium compounds are always present in the air as components of normal dust and dirt. The quantities vary seasonally and geographically, but in general they contribute little to the overall activity. However, decay products of the uranium and thorium series are introduced into the air through their rare gas descendents, radon and thoron, which diffuse from the earth into the air, and there set up their own decay series. In fact, the bulk of the natural radioactivity of the air is due to radon and its descendents, RaA, RaB, and RaC. Thoron and its descendents contribute much less, due to the short half-life of the parent rare gas and the consequently lower diffusion from the soil into the air.

In addition to these normal constituents of the air, there are a number of radioactive materials produced in the air through cosmic-ray activity. Among these exotic materials are tritium (H^3), carbon-14, and beryllium-7. If sufficiently large samples of the atmosphere could be obtained and analyzed satisfactorily, it should be possible to detect the vast number of radioisotopes which are formed by interaction of the cosmic-ray-produced neutrons with any of the elements in the earth's crust.

The folowing list indicates the relative importance of the radioactive components in terms of their contribution to the total radioactivity of the air:

1. Major
   a. Radon and its decay products

$$Rn^{222} \xrightarrow[3.8d]{\alpha} RaA\ (Po^{218}) \xrightarrow[3m]{\alpha} RaB\ (Pb^{214}) \xrightarrow[26.8m]{\beta^-} RaC\ (Bi^{214}) \xrightarrow[19.7m]{\beta^-} RaC'\ (Po^{214})$$

$$\xrightarrow[10^{-4}s]{\alpha} RaD\ (Pb^{210})\ (22y\ \text{half-life}).$$

*A recent report (1) reviews earlier work done in the USSR on atmospheric radioactivity and points out the desirability of conducting systematic studies on the natural radioactivity of the air.

b. Fission products in areas downwind of atomic explosions and shortly after detonation.

2. Secondary

a. Thoron and its decay products

$$\mathrm{Th(Rn^{220})} \xrightarrow[54s]{\alpha} \mathrm{ThA\ (Po^{216})} \xrightarrow[0.16s]{\alpha} \mathrm{ThB\ (Pb^{212})} \xrightarrow[10.6h]{\beta^-} \mathrm{ThC\ (Bi^{212})}$$

$$\xrightarrow{60.5m}\begin{cases}\xrightarrow{\beta^-} \mathrm{ThC'\ (Po^{212})} \xrightarrow[10^{-7}s]{\alpha} \\ \xrightarrow{\alpha} \mathrm{ThC''\ (Tl^{208})} \xrightarrow[3m]{\beta^-}\end{cases} \mathrm{Pb^{208}\ (stable).}$$

b. Gross fission products at locations some distance from atomic explosions. The isotopic composition varies with age, becoming progressively richer in such long-lived isotopes as Ce^{144}, Ru^{106}, Sr^{90}, and Cs^{137}.

3. Minor

a. Radium D decay series

$$\mathrm{RaD\ (Pb^{210})} \xrightarrow[22y]{\beta^-} \mathrm{RaE\ (Bi^{210})} \xrightarrow[5d]{\beta^-} \mathrm{RaF\ (Po^{210})} \xrightarrow[140d]{\alpha} \mathrm{Pb^{206}\ (stable).}$$

b. Individual fission products several weeks after atomic explosions.

c. Uranium, thorium, radium, and potassium from airborne dirt and dust.

d. Cosmic-ray-produced isotopes (H^3, Be^7, C^{14}, etc.).

EXPERIMENTAL PROCEDURE

NRL Atmospheric Radioactivity Monitor Equipment

For the past few years the U.S. Naval Research Laboratory has made routine measurements of the radioactivity of the air at a number of locations in the Northern Hemisphere (2). Some of this equipment is still in operation at several U.S. naval bases in the Northern Hemisphere, at Little America (operated by IGY/U.S. Weather Bureau personnel), and at Rio de Janeiro.

This equipment collects and measures activity at the collecting site. The operation involves drawing air through an efficient filter (100 percent for fission products, 75 percent for natural radioactive particulate matter such as RaB and C) for 24 hours and then measuring the rate of decay of the β-activity over the next 16 hours. The required data consists of an initial count of the filter (a 10-minute count immediately after removal from the blower) and one-hour counts from the 5th to 6th and 15th to 16th hours after the end of the initial count. From the ratios of these latter counts, there may be obtained the contribution of fission products to the total 16th hour count (2). After 5 hours, the contribution of the shorter-lived radon decay products is negligible. Since the half-life of the gross fission products is long compared to that of the thorium B (10.6 hours), the overall decay during the last 10 hours is essentially a measure of the thorium B+C present. Simple calculations give the counting rates of fission products and of the thorium B+C complex during the 16th hour. The procedure for calculating the actual radon, thoron, and fission-product concentrations per unit volume of air is given in Appendix A.

Filter Collections

Special collections of atmospheric radioactivity have been made with large filters (400 sq in.) and high-capacity blowers (2×10^6 cu ft per day). These collections have been analyzed for beryllium-7, lead-210, and polonium-210 using the analytical procedure outlined in Appendix B.

Other collections using smaller equipment are made routinely at a number of sites along the 80th meridian (west) as a part of the IGY program on Atmospheric Nuclear Radiation. These results are reported in Ref. 3.

Standardization of Counting Equipment

The counting rates of all samples have been corrected to disintegration rates by the use of factors derived from the measurement of known quantities of standardized radioisotopes each mounted with the appropriate amount of inactive carrier material. Mixed fission products have been assumed to have an average β-energy of 1 Mev.

RESULTS

Radon, thoron, and gross fission-product concentrations in the air have been calculated from data collected during 1957 by NRL Atmospheric Radioactivity monitor equipment located at Washington, D.C., Yokosuka, Japan, Rio de Janeiro, Brazil, Kodiak and Wales, Alaska, and Little America, Antarctica. Atmospheric radioactivity measurements using identical equipment are being made at San Francisco by the U.S. Naval Radiological Defense Laboratory.

Daily levels of radon, thoron, and gross fission products in the air at ground level during 1957 are reported in Tables 1-3* for Washington, Yokosuka, and Rio de Janeiro. Monthly averages are displayed graphically for collections made at Washington, Yokosuka, Kodiak, Wales, and Little America. Yearly averages of the airborne radioactivities at the above sites are reported in Table 4. The changes in the fission-product levels at the different sites during 1957 are plotted in Fig. 1. The extremely low activity of both fission-product and natural radioactivity at Little America and to a lesser extent at Kodiak and Wales, Alaska, prevents any very accurate determination of the levels of these products at these sites. However, the low levels of natural radioactivities enhance the detectability of an intrusion of fission products.

DISCUSSION OF RESULTS

The concentration of radioactive materials in the air at any given site varies widely from day to day due to the various local meteorological factors involved. Previous work at NRL (2) and elsewhere has shown the diurnal effect on the radon level in the air due to atmospheric inversions. This same process should operate to trap other radioactive material in a given area or to prevent the influx of air masses having greater or less activity. In addition to these short-term processes, there are seasonal factors which affect the levels of radon and thoron and should affect the long-term fallout of old fission debris from the stratosphere. Fission-product levels in the lower atmosphere, however, are most strongly influenced by the occurrence of nuclear tests in the appropriate geographical area.

*Tables 1-6 are at the end of the report.

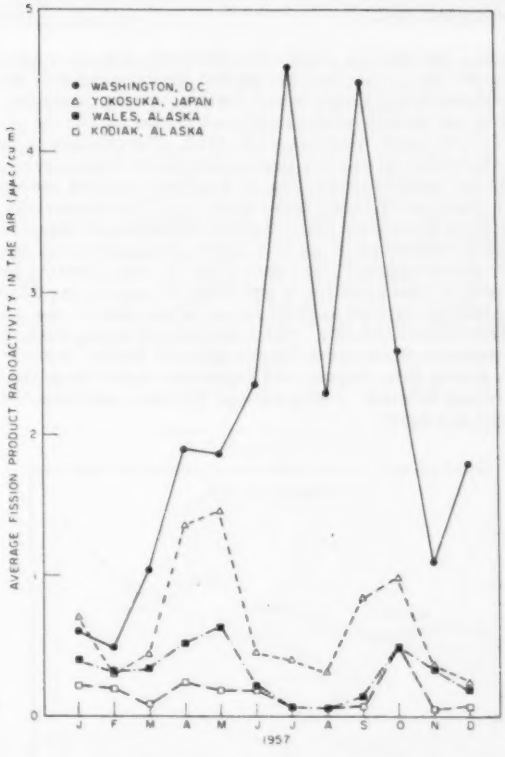

Fig. 1 - Variation of fission products in the air at the various measuring sites during 1957

Since during this study filters were replaced daily at 1530-1600 local time at most collecting sites (1300 at Wales, Alaska), the calculated radon concentrations represent that present between 1500-1600 local time (1200-1300 at Wales), near the time of minimal radon concentration. The calculated radon levels seem to be considerably higher than those reported in an earlier study (2). There are several reasons for this. During the previous study the air flow rate was assumed to be constant during the collecting period, while in this study the initial and final flow rates were measured with a flow meter (or pressure drop calibrated against a flow meter). In an area such as Washington, D.C., with moderately high dust loadings in the air, a considerable drop in air flow occurs toward the end of the collection with a corresponding direct influence on the radon decay products retained on the filter. Further, from the small quantity of data that has been processed to date, there is no assurance that either of the two studies has covered periods of "normal" concentrations of radon in the air.

Measurements at Washington, D.C.

At Washington, D.C., the monthly radon concentrations (**Fig. 2**) during the first part of the year 1957 remained fairly constant and showed the expected rise with warmer and drier weather. The extraordinarily high values obtained during November and December were perhaps related to the unusual weather patterns prevailing during this period. These values returned to more "normal" levels in early 1958. The changes in the thoron concentration with time seemed to be entirely independent of the radon levels, indicating perhaps that true equilibrium between thoron and its daughters had not been established prior to the collection. The close parallel of fission-product and thoron activity is extremely interesting and would seem to indicate that complete separation of these materials is not achieved by the analytical method used. In this method the assumption has been made that no decay of the fission products occurs during the 16-hour counting period. This would not be true if fresh fission products in any quantity were on the filter. The decay that takes place in the fission-product activity would be ascribed to the thoron and would thus lead to high apparent thoron activity. The effect of this decay would be of little significance in the determination of the gross fission-product levels, however. The high fission-product levels during July, August, and September result from the extensive nuclear tests at the Nevada Proving Grounds in May through October superimposed on debris from the USSR tests of March and April.

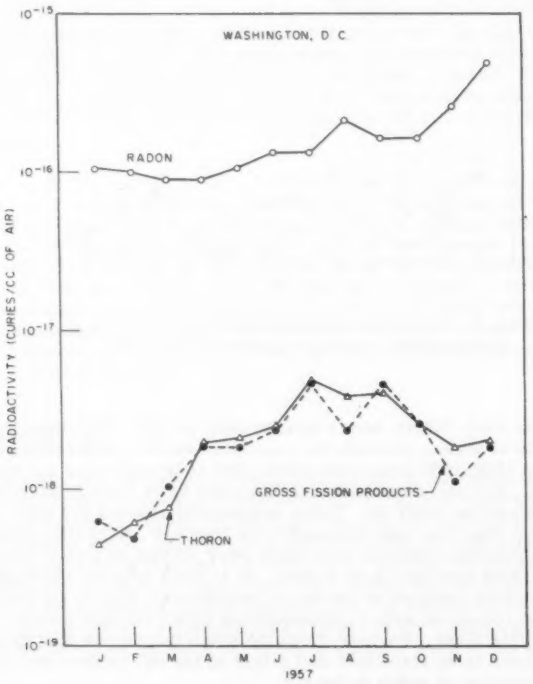

Fig. 2 - Monthly averages of the major radioactive products in the air at Washington, D.C., during 1957

Measurements at Yokosuka, Japan

At Yokosuka, Japan, radon levels (Fig. 3) were generally lower than at Washington during 1957 and, furthermore, reached a minimum during August. The expected increase in radon content in the summer months due to its increased diffusion from the warmer soil was more than compensated for by the increased rainfall during this season of the year. Thoron concentrations were somewhat lower relative to radon at Yokosuka than at Washington and generally seemed to follow more closely the changes in radon concentration. The fission-product level was completely independent of the thoron level and exhibited two major peaks (April-May and September-October) which coincided with the two major series of nuclear tests in the USSR. There seems to be little evidence that the extensive U.S. tests in Nevada during 1957 contributed significantly to this increase in the fission-product radioactivity in the air over Japan. The high rainfall during the summer months evidently served to cleanse the air passing over this area. The day-to-day changes in the radioactivity of the air at Yokosuka, as given in Table 2, may be compared with the announced dates of nuclear tests (Table 5).

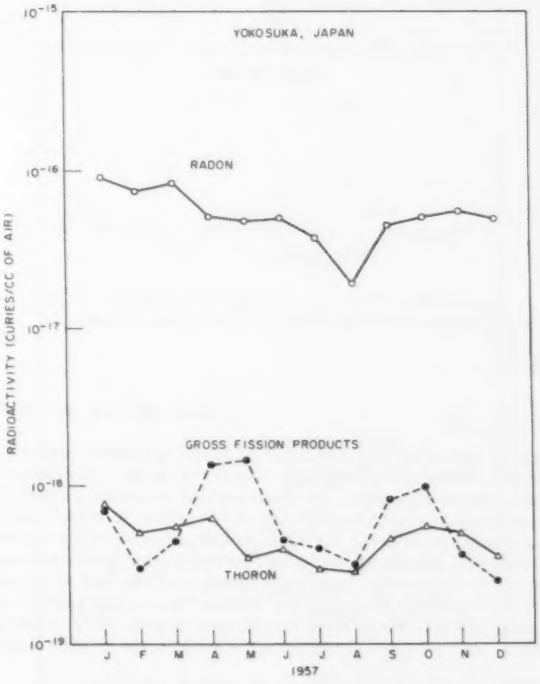

Fig. 3 - Monthly averages of the major radioactive products in the air at Yokosuka, Japan, during 1957

Measurements at Kodiak and Wales, Alaska

At Kodiak and Wales, Alaska, the level of radon and thoron activity (Figs. 4 and 5) was less than one-tenth that at Washington, D.C. The low values are due primarily to the relatively small uncovered land masses over which the prevailing winds pass on their way to these sites. Similar low values have been observed for island or coastal sites where the air comes mainly from the sea (2). Fission-product activity at these northern sites was much lower than at mid-latitudes. The first six months of the year exhibited higher activity due to the Russian nuclear tests; however, during the period of intensive U.S. testing in Nevada only low concentrations of fission products were detectible. Again, following the October USSR tests the level of fission products rose to a high value. In addition to the circulation patterns that discourage influx of material from the mid-latitudes into this more northerly region, there seems to be a mechanism at work which tends to clean the polar air or to replace it with cleaner air. This is in accord with general meteorological patterns which describe a general sinking of stratospheric air in the polar regions. These air masses, neglecting the direct introduction of fresh fission debris, would contain little or no radon and thoron, and the gross fission-product level would be low; further, these fission products should consist primarily of the longer-lived isotopes.

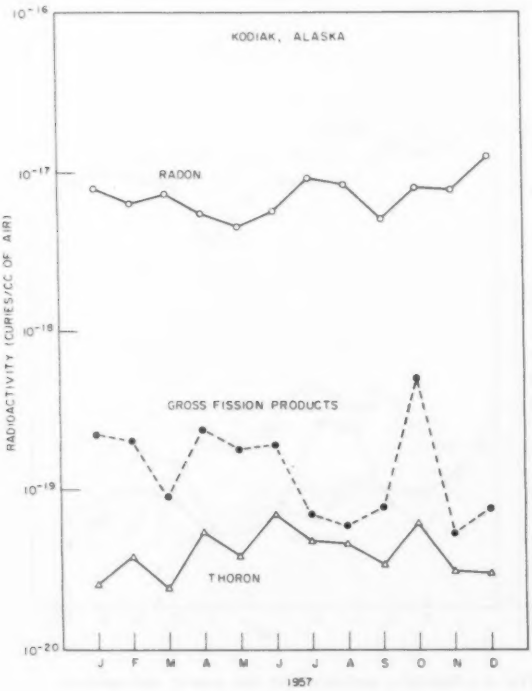

Fig. 4 - Monthly averages of the major radioactive products in the air at Kodiak, Alaska, during 1957

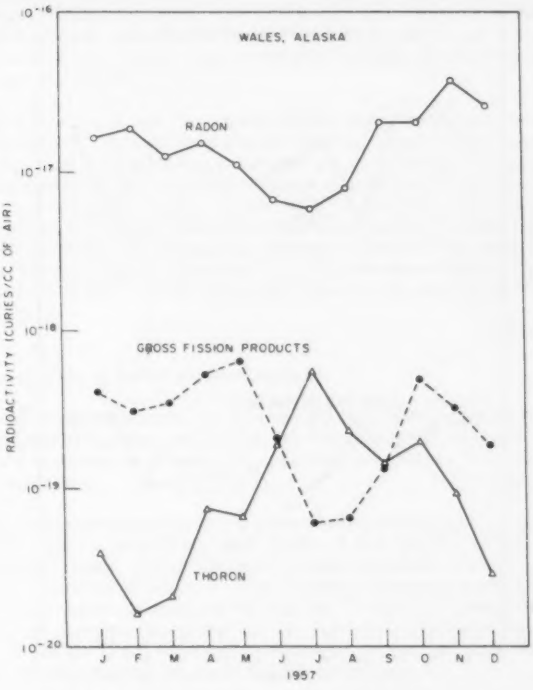

Fig. 5 - Monthly averages of the major radioactive products in the air at Wales, Alaska, during 1957

Measurements at Rio de Janeiro, Brazil

In the Southern Hemisphere it would be expected that the levels of radon and thoron activity would correspond to those at similar latitudes in the north, provided the stations were situated the same relative to land masses and prevailing winds. The available data from Rio de Janeiro (Table 3), collected by Dr. Bernhard Gross and Dr. Arthur Aron of the Instituto Nacional de Techologia, Rio de Janeiro, using equipment supplied by NRL, indicates that radon and thoron concentrations in the air during July and August are not too much different from the levels at Washington, D.C. The most striking, but not unexpected difference, is that the fission-product level is only about one-tenth that at Washington. The measurement is in accord with others made of the fission-product concentration in the air at various sites in the Southern Hemisphere along the 80th meridian (3).

Measurements at Little America, Antarctica

Data collected by IGY/U.S. Weather Bureau personnel at Little America using NRL-supplied air-monitor equipment indicates the radon concentration (Fig. 6) to be only about 20 percent that at Kodiak, Alaska, and the thoron content to be so low that no useful

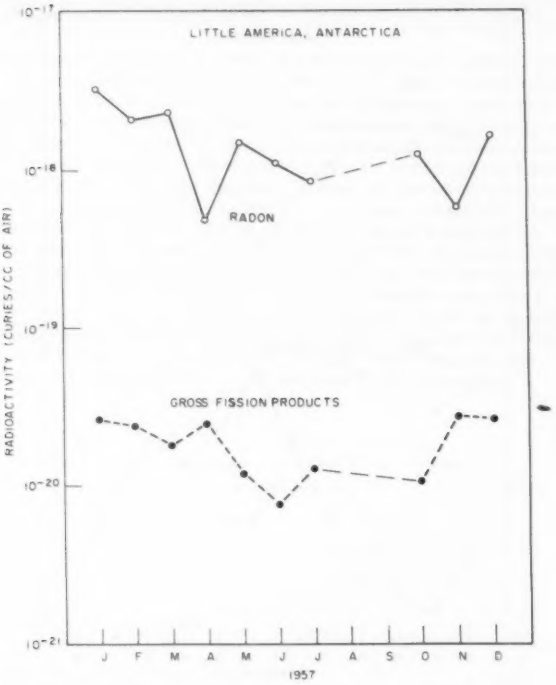

Fig. 6 - Monthly averages of the major radioactive products in the air at Little America, Antarctica, during 1957

measurements could be made (<0.01 $\mu\mu$c/cu m). The fission-product concentration was also extremely low, but measurable, and was about 10 percent of the level at Rio de Janeiro or Kodiak. The same explanations for these low activity levels hold true here as at Kodiak and Wales, Alaska, with the exceptions that there is practically no exposed land area in the vicinity and that no fission products have been intorduced near this latitude. In the absence of fresh debris, the concentrations of fission products at Kodiak (or Wales) and Little America should be of the same magnitude if there is uniform mixing within the stratosphere. Long-term measurements of this gross activity and isotopic analyses for such long-lived activities as Sr^{90} and Cs^{137} should throw some light on the extent of this mixing.

Relative Hazards of Fission Products in the Air

A word is in order about the effects of these radioactive products on the health and well-being of creatures living in their midst and drawing them into their metabolic cycles through ingestion. As an external hazard, these levels of fission products have never approached the level of radioactivity to which organisms have been continuously exposed since land masses emerged from the seas. It has been only on extremely rare occasions that the fission-product level in the air has approached that of radon alone. When one

considers that each radon atom gives rise to 3 α's, 2 β's and several γ's in its decay to the long-lived radium D, while each fission-product β, which has been measured, is accompanied by less than 1 γ, the relative external dosage of radiation due to the fission debris is even less significant.

The principal concern at this time about fallout involves the possible ingestion of significant quantities of Sr^{90} through food chains that might have concentrated the Sr^{90} to dangerous levels. This determination is outside the province of this work. However, it might be well to consider how much RaD is concentrated in animal bones since its air-to-ground cycle is in many ways similar to that of Sr^{90}. Further, radiochemical analyses currently underway at this Laboratory have indicated that the present levels of Sr^{90} and RaD in the air are of the same magnitude. Perhaps a study of the radon/radium D cycle from the atmosphere to animal bones would establish more suitable criteria for judging the long-term hazard of Sr^{90}, since the former equilibrium is already established in man's environment.

Radiochemical Analyses of Airborne Radioactivity

A study of the concentration of some of the higher yield fission products in the atmosphere at ground level at various sites along the 80th meridian (west) is currently underway as part of the IGY program on Atmospheric Nuclear Radiation. This work will be reported separately at a later date.

Some of the minor constituents of the normal atmosphere are the cosmic-ray-produced Be^7 and the Pb^{210} decay series (RaD, RaE, RaF). A few isolated analyses of Be^7 have been made to obtain a rough idea of its relative concentration in the air at ground level. These results are reported in Table 6. The analytical procedure employed was based on that of Arnold and Al-Salih (4) modified so that Pb^{210} and Po^{210} could be obtained in high yield from the same samples (see Appendix B). The Be^7 activity is somewhat higher than that of Pb^{210} (or Sr^{90}) but the number of atoms present per unit volume is lower by a factor of 50 to 100 because of its short (53.6d) half-life.

A preliminary study has been made of the Po^{210}/Pb^{210} activity ratios in several collections to determine the feasibility of using these ratios for estimating the apparent washout times of material in the lower atmosphere. The chemical procedure contains uncertainties because of the ease with which carrier-free polonium may be lost. Further, the indefinite period during which the RaD may have been building up from the radon makes interpretation of the ratios in terms of effective life-times of the material in the air most difficult. As a first approximation, the Po^{210}/Pb^{210} ratios obtained from the corresponding radioactivities listed in Table 6 give effective life-times of 4 to 30 days which agree roughly with the 15-day life-time previously calculated from radon/radium D ratios (5).

CONCLUSIONS

This report makes available direct comparisons of the major contributors to the radioactivity of the air measured at widely separated sites using identical equipment and techniques. Further, the tabulated daily data pertaining to such measurements presents the only information which shows the extreme variations to be expected by short-term measurements of radioactivity – both natural and fission-product – in the air.

Comparisons of fission-product levels at similar latitudes of the Northern and Southern Hemispheres show roughly ten times higher activity in the Northern Hemisphere during 1957. To date there is no evidence to indicate complete mixing of materials of the two hemispheres above the tropopause, but completely suitable measurements have not been possible because of the constant introduction of fresh atomic debris into the lower atmosphere through nuclear testing.

The increase in the total radioactivity of the air due to nuclear testing is negligible when compared with the normal activity levels due to natural products. The atmosphere does, however, serve as the medium by which fission products are distributed over the earth's surface and, therefore, a knowledge of the fission-product concentration in the air as well as meteorological data is necessary to interpret and to predict long-range fallout patterns.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the many individuals who have operated and maintained the NRL atmospheric radioactivity-monitoring equipment often under very trying conditions, and to Mr. Walter L. Anderson of NRL for his help in compiling the data.

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Appendix A
Determination of the Principal Radioactive Components in the Air From Measurement of the Rate of Decay of β-Activity Collected on Air Filters

If an initial β-count of short duration (10 to 15 minutes) is taken of a filter immediately following the cessation of the air flow, this count will be composed essentially of the individual counting rates of the radium B+C complex with a 26-minute half-life, of the thorium B+C complex with a 10.6-hour half-life, and of the fission products with an effective half-life greatly in excess of 10.6 hours. The counting rate of the fission products and the ThB+C complex can be determined for the 16th hour from the ratios of the 6th to 16th hour counting rates (see Table A1); therefore, the counting rate of the RaB+C complex may be found from the following simple relation:

$$C_r = C_i - C_f - (C_{16} - C_f)\, e^{-\lambda t}$$

where C_r = counting rate of RaB+C complex at approximately 6 minutes after collection,

C_i = average counting rate during 10-minute initial count,

C_f = counting rate of fission products,

C_{16} = average counting rate of sample from 15th to 16th hour,

λ = decay constant for ThB = 1.81×10^{-5} sec^{-1}, and

$t = 5.6 \times 10^4$ sec.

Table A1
Fission-Product Contribution to the 16th-Hour Count Determined from Ratio of 6th to 16th Hour Counts (Background Subtracted)

Fraction of 16th-Hour Count Due to Fission Products										
First Two Digits of Ratio	Last Digit of Ratio									
	0	1	2	3	4	5	6	7	8	9
1.0	1.00	0.99	0.98	0.97	0.96	0.95	0.94	0.92	0.91	0.90
1.1	0.89	0.88	0.87	0.86	0.85	0.84	0.83	0.82	0.80	0.79
1.2	0.78	0.77	0.76	0.75	0.74	0.73	0.72	0.71	0.70	0.69
1.3	0.67	0.66	0.65	0.64	0.63	0.62	0.61	0.60	0.59	0.58
1.4	0.56	0.55	0.54	0.53	0.52	0.51	0.50	0.49	0.48	0.47
1.5	0.46	0.45	0.43	0.42	0.41	0.40	0.39	0.38	0.37	0.36
1.6	0.35	0.34	0.33	0.31	0.30	0.29	0.28	0.27	0.26	0.25
1.7	0.24	0.23	0.22	0.21	0.19	0.18	0.17	0.16	0.15	0.14
1.8	0.13	0.12	0.11	0.10	0.09	0.08	0.06	0.05	0.04	0.03
1.9	0.02	0.01	0.00	-	-	-	-	-	-	-

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The measured counting rates of the samples are corrected for the counter efficiency for β-particles of different energies, and for the filter efficiency. Further, a radioactive standard is counted daily so as to take into account short-term changes in equipment sensitivity.

1. Radon Activity

Since the radon/radium B+C equilibrium is established within a matter of hours after diffusion of radon into the air, the radium B+C activity collected is proportional to the radon activity of the air. Further, since the rate of accretion of radium B atoms by the filter equals the rate of decay of radium B atoms on the filter at equilibrium, the following relation holds:

$$\text{Radon concentration (curies/cc of air)} = \frac{k\, D_r \lambda_r e^{\lambda_r t_2}}{V \gamma_r \left(1 - e^{-\lambda_r t_1}\right)}$$

where D_r = disintegration rate (d/s) of RaB+C at 6 minutes,

$\lambda_r = 4.3 \times 10^{-4}$ sec^{-1} decay constant of RaB,

t_1 = length of collection in seconds,

$t_2 = 3.6 \times 10^3$ sec = average decay time between collection and counting,

V = final air flow in cc/sec,

$\gamma_r = 2.3$ = activity of radium B+C complex (including conversion electrons) relative to the radon parent, and

$k = 2.7 \times 10^{-11}$ curies per d/s.

2. Thoron Activity

If the rate of diffusion of thoron from the soil and hence its concentration in the air is assumed to have been constant sufficiently long for ThB to have reached its equilibrium concentration, then for each decay of a thoron atom in the air there will occur, on the average, a corresponding decay of each descendent in the series. Further, the disintegration rate of the thorium B+C complex on the filter will be directly related to the rate of acquisition of thorium B atoms by the filter. The equilibrium concentration of thoron in the air may, therefore, be determined from the following relation:

$$\text{Thoron concentration (curies/cc of air)} = \frac{k\, D_t \lambda_t e^{\lambda_t t_2}}{V \gamma_t \left(1 - e^{-\lambda_t t_1}\right)}$$

where D_t = disintegration rate (d/s) of ThB+C at 6 minutes,

$\lambda_t = 1.81 \times 10^{-5}$ sec^{-1} decay constant of ThB,

t_1 = length of collection in seconds,

$t_2 = 5.6 \times 10^4$ sec = average decay time between collection and counting,

V = average air flow (cc/sec) for final day of collection,

γ_t = 2.73 activity of ThB+C complex (including conversion electrons) relative to the thoron parent, and

$k = 2.7 \times 10^{-11}$ curies per d/s.

3. Gross Fission-Product Activity

If it is assumed that the fission-product conglomerate on the filter is sufficiently old that no appreciable decay takes place during the period of collection and measurement, the average fission-product concentration is given by the following relation:

$$\text{Fission-product concentration (curies/cc of air)} = \frac{k\, D_f}{V}$$

where D_f = disintegration rate (d/s) of fission products,

V = volume of air (cc) passing through filter, and

$k = 2.7 \times 10^{-11}$ curies per d/s.

From the above analytical scheme it is apparent that the radon concentration is representative of only the last hour or two of the collection, while the thoron concentration is representative of the last day of a long collection. The rate of collection of fission products is assumed to be proportional to the air flow rate so that the calculated fission-product concentration is the average during the entire collection period. Due to the decreased flow that often occurs toward the end of long collections, this will tend to discriminate against fission products that arrive near the end of the collection period.

* * *

Appendix B
Radiochemical Separation of Bi^{210}, Po^{210}, and Be^{7} from Air-Filter Collections

INTRODUCTION

Air-filter samples for these analyses were made by means of 7-1/2-hp turbine blowers which filter about 5×10^4 cu m of air in 24 hours. The filter used was Army Chemical Corps Type-5 paper which consisted of cellulosic material and asbestos and had an exposed area of about 2600 sq cm.

It was found that a simple 6N HCl digestion of the filter paper in the presence of all carriers was adequate to dissolve the radiobismuth, lead, and polonium, while complete solution of the residue was necessary to dissolve the radioberyllium. This was confirmed by the analysis of filter papers over five years old whereby the d/m of Po^{210} isolated was found to equal the d/m of Bi^{210}. The latter requirement for complete solution of the residue for Be^{7} determinations was confirmed by the analysis of recent filter paper collections, in which case as much as 40 percent of the radioberyllium remained with the residue.

To comfirm further that a 6N HCl digestion completely dissolves radiobismuth, lead, and polonium, additional bismuth carrier was added to the filtered residue which was then dissolved by HF and H_2SO_4 digestion followed by a Na_2CO_3 fusion of the remaining insoluble residue. The bismuth which was subsequently isolated did not contain any β-activity.

Polonium begins to volatilize around 200°C, so all operations were held below this temperature during its separation. Since bismuth carries Po^{210} as well as Bi^{210}, the radiochemical purification of the bismuth is completed up to the point of separating the two so that an accurate determination of the chemical recovery of both may be made.*

PROCEDURE

A 24-hour filter paper collection which weighed about 50 g was transferred to a 3-liter beaker and digested for 30 minutes at 80° to 90°C with 600 ml of 6N HCl along with Bi, Be, Pb, Ce, Y, and Zr carriers. After dilution, this was filtered and the residue washed with dilute HCl. The filtrate contained all the Pb^{210}, Bi^{210}, and Po^{210} and some of the Be^{7}. The residue was ashed at 550°C and digested with HNO_3–HF–H_2SO_4 mixture and evaporated to fumes of H_2SO_4. Any insoluble residue remaining after the salts were dissolved in dilute HCl was fused with $KHSO_4$ and the melt extracted with water. These solutions were combined with the original filtrate, the pH adjusted to about 3 with NaOH, and sulfides precipitated with H_2S.

The sulfide precipitate contained the Pb^{210}, Bi^{210}, and Po^{210} while the filtrate contained the Be^{7}.

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* Some general references are: J.R. Arnold and H.A. Al-Salih, Science 121:451-453 (1955); A.J. Cruikshank et al., Can. J. Chem. 34:214-219 (1956); H.V. Moyer, "Polonium," AEC Report TID-5221, July 1956.

Treatment of the Sulfide Precipitate

The sulfides were dissolved in dilute HNO_3 and the bismuth separated from the lead as BiOCl. The time was noted since Bi^{210} decays from this point on. After a series of BiOCl and Bi_2S_3 precipitations were made with appropriate holdbacks, several $(NH_4)_2S$-acid Bi_2S_3 cycles were performed to decontaminate from Sb and Te fission-product activities. The bismuth was finally recovered as BiOCl, dissolved in 1.5N HCl, and the Po^{210} plated out spontaneously onto a silver disk at 95°C for two hours.* Both sides of the disk were counted for α-activity in a methane proportional flow counter. The disk was also checked for β-activity which was invariably found to be background. The Po^{210} activity was corrected for buildup from the time the air-filter collection was made.

Bismuth was recovered from the Po-plating solution as Bi_2S_3, converted to the basic carbonate, and ignited to Bi_2O_3 in which form it was counted for β-activity. Its activity was corrected for decay to the time of separation from Pb^{210}.

Treatment of the Sulfide Filtrate

The H_2S was expelled from the filtrate by boiling. This filtrate contained macro quantities of Al, Fe, and Ca as well as carrier beryllium. The solution was made 2N with respect to NaOH, and the $Fe(OH)_3$ filtered off and discarded. The pH of the filtrate was adjusted to about 6 and the precipitated $Al(OH)_3$ and $Be(OH)_2$ recovered by filtration. Most of the Al was removed as $AlCl_3$ by saturating the HCl–diethyl ether solution of the Al–Be precipitate with HCl gas†. The remaining Al was removed as aluminum quinolate‡ and the Be recovered as $Be(OH)_2$.

The Be was purified from Ru γ-activity by successive evaporations with $HClO_4$ and Ru carrier, RuO_4 being volatilized. It was further purified from other fission-product activities by acid sulfide and $Fe(OH)_3$ sweeps. The final $Be(OH)_2$ precipitate was ignited to BeO, weighed to determine chemical recovery (usually 65 percent) and then counted in a scintillation spectrometer, using a 2-in. NaI (Tl) well crystal, at a channel setting admitting the full photopeak of Be^7. Its purity was confirmed further by half-life measurements (53.6d) and by noting the absence of β-activity using a GM detector.

*M. Frisch and I. Feldman, "A Note on Precision Plating of Polonium," University of Rochester Report UR-426, Feb. 1956; F.A. Smith et al., "Analytical and Antoradiographic Methods for Polonium ^{210}," University of Rochester Report UR-305, Nov. 1955

†N.H. Furman, editor, "Scott's Standard Methods of Chemical Analysis," New York: D. Van Nostrand, pp. 12, 13, 1939

‡G.E.F. Lundell and J.I. Hoffman, "Outlines of Methods of Chemical Analysis," New York: Wiley, pp. 113-116, 1938

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Table 1
Daily Atmospheric Radioactivity Measurements
at Washington, D.C., 1957

(Filter: ACC Type-5 Collections end at 1600 local time)					
Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity ($\mu\mu$c/cu m of air)		
			Radon	Thoron	Fission Products
Jan 2	48	0	53	0.44	0.80
3	24	0	75	0.41	0.60
4*	24	0	99	0.98	0.45
7*	72	5.1	133	0.63	0.57
8	24	0	141	0.16	0.79
9	24	5.6	148	0.50	0.94
10*	24	3.8	148	0.63	0.35
11*	24	0	55	0.54	0.94
14*	72	2.5	80	0.13	0.57
15*	24	0	54	0.36	0.73
16*	24	2.8	65	0.09	0.54
17*	24	1.0	123	0.14	0.84
18*	24	0.3	88	0.37	0.38
22*	96	0	170	0.56	0.40
23*	24	7.9	106	0.26	0.39
24*	24	0	68	0.25	0.90
25*	24	0.3	64	0.55	0.95
28*	72	8.1	143	0.72	0.74
29*	24	6.6	220	0.74	0.37
30*	24	0	35	0.34	0.37
31*	24	0	135	0.66	0.40
Feb 1*	24	8.4	137	0.61	0.19
4*	72	6.6	78	0.25	0.25
5*	24	0	141	0.36	1.11
6*	24	4.8	175	0.42	0.79
7*	24	0	137	0.61	0.33
8*	24	7.4	193	0.72	0.41
11*	72	0	91	0.78	0.47
12*	24	0	38	0.59	1.03
13*	24	0	88	0.58	1.09
14*	24	19.3	61	0.68	1.03
15*	24	38.8	66	0.37	0.32
18*	72	0	152	1.57	0.45
19	Equipment failure				
20	Equipment failure				
21	24	0.5	64	0.46	0.74
25	96	0	110	0.28	0.12
26	24	14.7	34	0.92	0.90
27	24	0.3	10	0.35	0.28
28	24	19.8(s)	118	0.85	0.37
Mar 1	24	3.3(s)	165	0.72	0.66
4	72	0	53	0.28	0.58
5	24	0	37	0.74	0.53
6	24	0	49	0.78	0.72
7	24	4.1	93	0.75	1.05

* Note: See footnotes at end of table.

(Table continues)

Table 1 (Continued)
Daily Atmospheric Radioactivity Measurements
at Washington, D.C., 1957

(Filter: ACC Type-5 Collections end at 1600 local time)

Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity ($\mu\mu$c/cu m of air)		
			Radon	Thoron	Fission Products
Mar 8	24	6.6	76	0.35	0.59
11	72	9.4	84	0.95	0.63
12	24	0	119	1.03	1.65
13	-	0	No data obtained		
14	7	0	58	0.16	1.14
15	24	1.8	71	0.70	5.2
18	72	11.7	109	0.86	1.65
19	24	10.4	78	0.47	0.88
20	24	0	120	0.84	0.28
21	24	0	107	0.62	0.26
22	24	0	99	1.28	0.80
25	72	2.0	54	0.70	1.10
26	24	0	87	0.67	1.51
27	-	1.8	Equipment failure		
28	24	0	152	1.22	0.13
29	24	0	104	1.40	0.51
Apr 1	72	0	61	1.10	1.08
2	24	17.0	139	0.76	1.69
3	24	0	55	0.88	0.69
4	24	2.5	41	0.63	1.42
5	24	14.5	108	0.70	0.68
8	72	11.7	111	1.55	0.81
9	24	5.3	39	0.82	2.0
10	24	0	72	1.45	2.0
11	24	0	127	2.4	1.97
12	24	0	Equipment failure		
15	72	1.3	Equipment failure		
16	24	0	85	1.69	2.7
17	24	0	42	0.72	1.77
18	24	1.3	146	4.4	3.7
19	24	0	110	2.1	2.5
22	72	0	91	3.0	1.76
23	24	0.8	129	1.73	0.76
24	24	0	72	3.7	1.94
25	24	0	117	3.4	5.0
26	24	0	134	1.98	1.74
29	72	0	53	2.9	2.1
30	24	0	79	3.7	3.6
May 1	24	0	43	2.8	4.5
2	24	0	Equipment failure		
3	24	0	Equipment failure		
6	72	0	125	3.3	1.59
7	24	0	82	4.0	4.4
8	24	0	83	3.8	3.4
9	24	0	144	2.5	4.1

*Note: See footnotes at end of table.

Table 1 (Continued)
Daily Atmospheric Radioactivity Measurements
at Washington, D.C., 1957

(Filter: ACC Type-5 Collections end at 1600 local time)					
Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity ($\mu\mu$c/cu m of air)		
			Radon	Thoron	Fission Products
May 10	24	0	153	2.7	3.1
13	72	0	122	2.3	2.6
14	24	2.8	155	1.7	1.76
15	24	13.2	114	0.96	1.45
16	24	0	73	1.5	2.1
17	24	0	83	1.9	1.17
20	72	0	131	0.81	1.29
21	24	0.3	119	1.06	0.18
22	24	0	92	1.08	0.39
23	24	0	162	1.6	0.45
24	24	0	106	1.22	1.71
27	72	0.5	189	1.7	1.18
28	24	0	54	0.98	0.95
29	24	0	76	4.3	1.55
31	48	0	43	2.1	1.38
June 3	72	5.3	75	0.71	1.6
4	24	0	121	1.3	1.4
5	24	32.3	65	1.1	0.73
6	24	12.9	Equipment failure		
7	24	0	250	0.89	2.8
10	72	3.3	22	0.73	1.5
11	24	0	73	1.6	2.5
12	24	0.3	230	1.5	2.0
13	24	0	190	4.7	2.6
14	24	0	190	2.0	2.3
17	72	8.4	Equipment failure		
18	24	0	180	4.3	1.4
19	24	0	160	2.6	1.20
20	24	0	122	2.0	0.83
21	24	0	200	1.8	1.4
24	72	3.3	120	6.7	6.5
25	24	1.5	180	2.6	7.3
26	24	0.5	170	2.6	2.5
27	24	0	56	3.9	20.0
28	24	0	121	3.2	19.7
July 1	72	0	55	1.8	1.59
2	24	0	67	1.9	0.92
3	-	Power failure			
5	48	0	115	2.4	1.96
8	72	0	300	5.9	1.39
9	24	1.8	248	4.2	3.0
10	24	0	58	2.5	4.0
11	24	0	63	2.4	0.75
12	24	0	Equipment failure		
15	72	0	79	9.1	3.9

*Note: See footnotes at end of table.

(Table continues)

Table 1 (Continued)
Daily Atmospheric Radioactivity Measurements
at Washington, D.C., 1957

(Filter: ACC Type-5 Collections end at 1600 local time)					
Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity ($\mu\mu$c/cu m of air)		
			Radon	Thoron	Fission Products
July 16	24	0	95	2.5	1.53
17	24	0	195	4.9	0.89
18	24	0	104	2.5	0.76
19	24	0	77	4.1	1.06
22	72	0	280	13.5	6.7
23	24	1.3	200	8.0	22.0
24	24	7.6	63	1.4	1.20
25	24	0	75	2.8	0.89
26	24	0	130	5.3	1.03
29	72	0	187	5.5	5.4
30	24	0	159	5.2	11.6
31	24	11.4	310	12.9	26.9
Aug 1	24	0	126	11.8	21.0
2	24	0	104	5.1	2.9
5	72	6.9	184	4.7	4.1
6	24	0	104	3.7	1.24
7	24	0	132	4.9	0.93
8	24	0	117	5.7	1.31
9	24	0	322	3.6	1.30
12	72	0	930	10.0	1.58
13	24	0	13	1.34	3.7
14	24	0	Equipment failure		
15	24	0	120	1.92	2.35
16	24	0	268	2.7	1.48
19	72	4.8	97	1.54	0.62
20	24	0	129	2.5	1.06
21	24	0	143	5.9	0.94
22	24	0	129	2.8	0.70
23	24	0	33	1.06	0.37
26	72	33.0	497	2.8	1.01
27	24	0	266	3.1	1.94
28	24	0	160	2.9	2.1
29	24	0	194	2.7	0.45
30	24	0	450	3.1	1.48
Sept 3	96	6.3	250	3.6	2.3
4	24	11.7	390	5.3	13.2
5	24	0	72	9.2	6.6
6	24	0	240	5.7	5.2
9	72	1.0	197	29.0	16.3
10	24	5.8	53	3.2	7.9
11	24	0	Equipment failure		
12	24	0	Equipment failure		
13	24	2.5	145	2.0	2.2
16	72	15.5	88	2.1	3.4
17	24	42.0	380	0.81	3.9

*Note: See footnotes at end of table.

Table 1 (Continued)
Daily Atmospheric Radioactivity Measurements
at Washington, D.C., 1957

(Filter: ACC Type-5 Collections end at 1600 local time)					
Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity (μc/cu m of air)		
			Radon	Thoron	Fission Products
Sept 18	24	0	184	1.43	1.32
19	24	0	116	1.10	1.77
20	24	0	151	1.32	4.1
23	72	0	113	0.90	2.0
24	24	0	83	2.1	5.8
25	24	0	114	4.6	1.65
26	24	0	280	4.5	2.3
27	24	0	64	0.19	1.94
30	72	trace	138	1.92	0.56
Oct 1	24	trace	150	1.78	2.9
2	24	0	Equipment failure		
3	24	0	53	3.2	1.68
4	24	0	Equipment failure		
7	72	12.7	100	0.83	1.36
8	24	trace	128	1.27	1.56
9	24	trace	87	1.70	5.3
10	24	0	132	2.7	5.5
11	24	0	63	1.28	1.91
14	72	0	240	2.5	0.93
15	24	0	161	5.7	5.0
16	24	0	174	5.5	4.3
17	24	0.3	202	2.4	4.9
18	24	12.7	320	2.1	2.0
21	72	0	370	7.4	0.95
22	24	0	153	2.1	3.4
23	24	0	143	3.4	3.9
24	24	7.6	101	0.77	3.7
25	24	4.8	120	0.72	0.70
28	72	0	114	1.53	3.1
29	24	0	168	3.5	3.9
30	24	0	320	2.3	2.9
Nov 1	48	3.6	230	3.0	2.5
4	72	14.5	152	1.52	0.67
5	24	0	163	1.11	1.55
6	24	0	102	0.80	0.61
7	24	0	100	1.6	0.57
8	24	0	350	0.94	1.42
12	96	5.8	132	2.9	1.06
13	24	0	191	3.8	1.37
14	24	1.3	280	1.45	1.58
15	24	7.1	380	0.70	1.23
18	72	2.5	123	1.16	0.55
19	24	9.4	160	0.50	0.59
20	24	0	134	0.44	0.67
21	24	0	210	1.16	0.66

*Note: See footnotes at end of table.

(Table continues)

Table 1 (Continued)
Daily Atmospheric Radioactivity Measurements
at Washington, D.C., 1957

(Filter: ACC Type-5 Collections end at 1600 local time)					
Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity ($\mu\mu$c/cu m of air)		
			Radon	Thoron	Fission Products
Nov 22	24	trace	490	2.2	1.36
25	72	6.6	420	1.95	1.00
26	24	0	510	3.0	1.46
27	24	0	390	4.3	1.12
29	48	6.9	500	1.66	1.95
Dec 2	72	0	2400	1.07	1.34
3	24	0	460	2.8	2.9
4	24	30.5(s)	161	0.68	1.01
5	24	0	300	0.53	1.32
6	24	trace	410	1.54	1.90
9	72	35.3	710	1.84	1.55
11	48	2.3	197	1.60	0.73
12	24	0	216	0.94	0.71
13	24	0	370	1.22	1.05
16	72	trace	850	2.0	1.48
17	24	0	470	2.9	4.3
18	24	0	410	2.3	1.67
19	24	0.3	430	1.53	2.3
20	24	17.0	92	1.48	2.5
23	72	0	199	4.8	1.91
24	24	0	320	1.54	3.2
26	48	29.4	420	1.34	2.1
27	24	0.3	390	0.96	2.6
30	72	0.8	480	4.4	2.1
31	24	0	680	4.3	1.53

*No air flow data available: Rates assumed to decrease to 80 percent after 1 day; 60 percent after 2 days; 40 percent after 3 days; etc.

(s) as snow

Table 2
Daily Atmospheric Radioactivity Measurements
at Yokosuka, Japan, 1957

(Filter: ACC Type-5 Collection usually ended at 1530 local time)					
Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity (μc/cu m of air)		
			Radon	Thoron	Fission Products
Jan 1	24	0	68	0.62	0.37
2	24	0	114	0.70	0.54
3	24	trace	122	1.13	1.04
4	24	0	189	0.97	0.76
5	24	0	52	0.51	0.62
6	24	0	114	0.63	0.43
7	24	0	68	0.59	0.47
8	24	0	113	0.68	0.51
9	24	0	70	0.78	0.73
10	24	0	85	0.77	0.94
11	24	0	133	0.76	0.52
12	24	0	112	1.02	0.17
13	24	0	61	0.34	0.56
14	24	0	67	0.67	0.70
15	24	trace	66	0.37	0.90
16	24	0	58	0.87	0.54
17	24	0	75	0.63	0.73
18	24	0	86	1.12	1.56
19	24	trace	111	1.06	1.3
20	24	trace	141	1.00	0.79
21	24	0	103	0.85	0.43
22	24	0	67	0.73	0.25
23	24	0	58	0.97	0.58
24	24	0	67	0.38	0.69
25	24	trace	23	1.01	0.57
26	24	0	87	0.97	0.53
27	24	trace	136	0.29	1.65
28	24	0	87	0.84	0.91
29	24	7.1	72	1.42	1.24
30	24	20.0	-	0.58	0.71
31	24	0.5	87	0.50	0.20
Feb 1	24	0	75	0.54	0.23
2	24	0	73	0.68	0.31
3	24	35.6	150	0.90	0.71
4	24	1.0	47	0.24	0.14
5	24	0	73	0.71	0
6	24	5.6	57	0.29	0.28
7	24	13.7	74	0.40	0.77
8	24	7.6	33	0.23	0.06
9	24	trace	77	0.76	0.03
10	24	trace	127	0.71	0.05
11	24	trace	112	0.60	0.08
12	24	0	92	0.36	0.28
13	24	0	62	0.48	0.47
14	24	0	62	0.62	0.49
15	24	0	Equipment failure		

(Table continues)

Table 2 (Continued)
Daily Atmospheric Radioactivity Measurements
at Yokosuka, Japan, 1957

(Filter: ACC Type-5 Collection usually ended at 1530 local time)					
Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity ($\mu\mu$c/cu m of air)		
			Radon	Thoron	Fission Products
Feb 16	24	9.1	98	0.73	0.52
17	24	trace	68	0.38	0.32
18	24	0	71	0.43	0.34
19	24	1.8	63	0.21	0.36
20	24	0	50	0.35	0.17
21	24	0	59	0.53	0.32
22	24	trace	29	0.35	0.14
23	24	0.8	47	0.23	0.21
24	24	0	108	0.21	0.35
25	24	trace	56	0.69	0.47
26	24	0	77	1.12	0.52
27	24	0	68	0.70	0.38
28	24	trace	81	0.57	0.22
Mar 1	24	0	104	0.56	0.26
2	24	0	89	0.69	0.22
3	24	trace	93	0.83	0.25
4	24	trace	35	0.79	0.18
5	24	22.8	118	0.62	0.32
6	24	trace	134	0.36	0.29
7	24	0	68	0.35	0.43
8	24	37.6	145	0.97	0.53
9	24	0	115	0.31	0.16
10	24	0	84	0.25	0.63
11	24	trace	94	0.43	0.65
12	24	trace	64	0.37	0.26
13	24	0	65	0.32	0.46
14	24	trace	62	0.38	0.35
15	24	0	35	0.39	0.27
16	24	0	59	0.57	0.26
17	24	0	66	0.99	0.83
18	24	0	77	0.71	0.42
19	24	0	68	0.85	0.41
20	24	0	82	1.11	0.37
21	24	0	58	0.51	0.59
22	24	0	70	0.20	0.31
23	24	0.5	-	0.48	0.59
24	24	2.0	107	1.07	0.54
25	24	0	63	0.35	0.24
26	24	trace	88	0.88	0.38
27	24	0	61	0.48	0.34
28	24	1.3	62	0.93	0.34
29	24	0.3	46	0.25	0.44
30	24	0	33	0.35	1.08
31	24	trace	170	0.05	1.54
Apr 1	24	0	75	0.53	0.54

Table 2 (Continued)
Daily Atmospheric Radioactivity Measurements
at Yokosuka, Japan, 1957

(Filter: ACC Type-5 Collection usually ended at 1530 local time)					
Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity ($\mu\mu$c/cu m of air)		
			Radon	Thoron	Fission Products
Apr 2	24	0	127	0.68	0.54
3	24	0	50	0.49	0.80
4	24	0	38	0.60	0.53
5	24	0	60	0.59	0.69
6	24	0	57	1.11	0.83
7	24	0	55	1.14	1.06
8	24	0	24	0.38	1.17
9	24	0	20	0.23	0.81
10	24	trace	45	0.88	1.53
11	24	0	33	0.66	0.92
12	24	12.7	9	0.36	0.90
13	24	2.5	-	0.26	0.40
14	24	23.1	36	0.55	0.88
15	24	0	68	0.51	1.15
16	24	0	63	2.3	4.7
17	24	2.0	41	0.91	2.1
18	24	0	55	0.69	1.43
19	24	3.8	31	0.20	0.98
20	24	19.0	21	0.18	0.54
21	24	trace	110	0.95	5.5
22	24	21.6	62	0.55	3.2
23	24	45.2	31	0.28	0.63
24	24	0.3	26	0.28	0.24
25	24	10.7	19	0.25	0.77
26	24	0	72	0.43	0.29
27	24	2.3	65	0.25	1.25
28	24	0	102	0.87	2.20
29	24	0	64	1.06	1.85
30	24	0	27	0.82	2.3
May 1	24	trace	27	0.25	2.4
2	24	10.9	37	0.46	3.4
3	24	0	68	0.20	1.15
4	24	0	53	0.20	1.13
5	24	1.3	14	0.20	2.0
6	24	7.9	66	0.33	1.05
7	24	14.5	76	0.42	1.28
8	24	14.5	80	0.58	1.45
9	24	0	57	0.32	0.90
10	24	0	34	0.15	1.12
11	24	2.8	18	0.34	1.21
12	24	15.5	-	0.27	2.0
13	24	0	24	0.12	0.85
14	24	3.6	74	0.71	3.4
15	24	0	66	0.43	1.02
16	24	0	76	0.66	1.50
17	24	0	59	0.74	1.67

(Table continues)

Table 2 (Continued)
Daily Atmospheric Radioactivity Measurements
at Yokosuka, Japan, 1957

(Filter: ACC Type-5 Collection usually ended at 1530 local time)

Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity ($\mu\mu$c/cu m of air)		
			Radon	Thoron	Fission Products
May 18	24	0	73	0.34	2.0
19	24	3.1	15	0.12	2.2
20	24	94.0	30	0.05	1.68
21	24	0	60	0.07	0.40
22	24	trace	41	0.22	1.26
23	24	0	24	0.27	0.49
24	24	0	24	0.53	1.45
25	24	38.1	88	0.30	1.74
26	24	0	51	0.41	0.42
27	24	0	23	0.45	1.25
28	24	0	32	0.52	1.45
29	24	4.6	55	0.23	1.32
30	24	25.7	69	0.46	1.15
31	24	0	27	0.43	1.33
June 1	24	0	58	0.18	1.31
2	24	trace	49	0.23	0.81
3	24	3.8	43	0.35	0.96
4	24	0	53	0.43	0.81
5	24	6.3	95	0.67	1.08
6	24	18.3	55	0.49	0.52
7	24	8.4	49	0.51	0.17
8	24	1.5	25	0.21	0.04
9	24	trace	-	0.38	0.13
10	24	0	28	0.22	0.33
11	24	3.8	35	0.67	0.40
12	24	36.6	49	0.40	0.32
13	24	trace	35	0.18	0.31
14	24	0	15	0.53	0.04
15	24	0	32	0.62	0.43
16	24	trace	96	0.35	0.43
17	24	1.3	32	0.58	0.43
18	24	48.3	26	0.36	0.54
19	24	0	84	0.36	0.75
20	24	0	86	0.34	0.64
21	24	trace	80	0.77	0.61
22	24	3.1	-	0.53	0.94
23	24	16.0	47	0.40	0.40
24	24	trace	32	0.12	0.31
25	24	4.3	62	0.41	0.23
26	24	1.3	65	0.67	0.25
27	24	188.	90	0.45	0.47
28	24	36.8	27	0.19	0.07
29	24	2.5	33	0.06	0.31
30	24	30.0	4	0.45	0.03
July 1	24	trace	16	0.46	0.04

Table 2 (Continued)
Daily Atmospheric Radioactivity Measurements
at Yokosuka, Japan, 1957

(Filter: ACC Type-5 Collection usually ended at 1530 local time)					
Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity ($\mu\mu$c/cu m of air)		
			Radon	Thoron	Fission Products
July 2	24	15.3	16	0.31	0.01
3	24	3.8	Equipment failure		
4	24	0	Equipment failure		
5	24	0	40	0.08	0.15
6	24	0	59	0.35	0.79
7	24	0.5	65	0.80	1.21
8	24	trace	Equipment failure		
9	24	7.9	17	0.21	0.16
10	24	42.1	26	0.23	0.21
11	24	4.1	15	0.33	0.68
12	24	10.2	28	0.39	0.63
13	24	1.5	47	0.41	0.29
14	24	trace	27	0.25	1.17
15	24	0	11	0.19	1.13
16	24	2.3	30	0.16	0.30
17	24	39.9	37	0.24	0.44
18	24	trace	29	0.19	0.33
19	24	trace	14	0.47	0.55
20	24	trace	116	0.23	0.71
21	24	12.9	60	0.43	0.13
22	24	7.6	43	0.06	0.31
23	24	1.8	47	0.24	0.17
24	24	trace	57	0.28	0.03
25	24	trace	58	0.42	0.48
26	24	50.0	56	0.27	0.37
27	24	0.8	3	0.23	0.54
28	24	0	13	0.05	0.20
29	24	0	30	0.22	0.18
30	24	trace	28	0.37	0.15
31	24	0	67	0.47	0.22
Aug 1	24	0	51	0.75	0.20
2	24	0	-	0.24	0.13
3	24	trace	18	0.36	0.23
4	24	trace	51	0.73	0.10
5	24	trace	15	0.32	0.12
6	24	10.1	1	0.13	0.22
7	24	0	18	0.18	0.31
8	24	19.3	21	0.22	0.25
9	24	trace	54	0.18	0.28
10	24	trace	31	0.15	0.72
11	24	5.8	2	0.16	0.16
12	24	0	2	0.34	0.32
13	24	0	2	0.12	0.14
14	24	trace	37	0.13	0.15
15	24	0	23	0.26	0.15
16	24	7.6	29	0.27	0.11

(Table continues)

Table 2 (Continued)
Daily Atmospheric Radioactivity Measurements
at Yokosuka, Japan, 1957

(Filter: ACC Type-5 Collection usually ended at 1530 local time)

Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity ($\mu\mu$c/cu m of air)		
			Radon	Thoron	Fission Products
Aug 17	24	0	Equipment failure		
18	24	0	Equipment failure		
19	24	trace	5	0.21	0.21
20	24	0.3	5	0.19	0.36
21	24	3.3	2	0.24	0.13
22	24	2.5	2	0.09	0.11
23	24	0	3	0.11	0.07
24	24	trace	10	0.13	0.04
25	24	0	36	0.14	0.26
26	24	0	44	0.89	0.31
27	24	0	5	0.31	0.10
28	24	0	1	0.09	0.30
29	24	2.0	23	0.14	0.66
30	24	0	26	0.63	1.19
31	24	0	34	0.80	2.0
Sept 1	24	1.5	59	0.72	1.50
2	24	4.6	-	0.31	0.28
3	24	trace	47	0.24	0.24
4	24	0	43	0.41	0.13
5	24	0	32	0.52	0.27
6	24	37.6	53	0.49	0.45
7	24	67.5	5	0.16	0.10
8	24	0	30	0.13	0.10
9	24	10.1	45	0.24	0.19
10	24	27.7	49	0.26	0.24
11	24	41.9	80	0.38	0.65
12	24	19.3	21	0.25	0.37
13	24	8.9	59	0.20	0.50
14	24	10.1	72	0.57	1.77
15	24	trace	Equipment failure		
16	24	30.0	28	0.49	0.69
17	24	34.0	36	0.58	2.1
18	24	0	24	1.46	0.43
19	24	0	28	0.42	1.28
20	24	trace	28	0.98	0.91
21	24	trace	34	0.65	1.14
22	24	0	102	0.23	1.69
23	24	0	44	0.19	1.87
24	24	0	9	0.71	1.24
25	24	66.0	50	0.55	2.3
26	24	8.9	42	0.34	0.86
27	24	11.7	64	0.35	0.44
28	24	0	50	0.68	1.02
29	24	17.3	70	0.68	0.79
30	24	19.8	48	0.14	0.81

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Table 2 (Continued)
Daily Atmospheric Radioactivity Measurements
at Yokosuka, Japan, 1957

(Filter: ACC Type-5 Collection usually ended at 1530 local time)					
Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity (μμc/cu m of air)		
			Radon	Thoron	Fission Products
Oct 1	24	1.8	125	0.50	1.12
2	24	0	48	0.49	1.01
3	24	0	35	0.35	0.97
4	24	0	75	0.48	1.08
5	24	3.8	35	0.44	0.77
6	24	130.	37	0.95	1.42
7	24	trace	34	0.33	0.52
8	24	0	Equipment failure		
9	24	0	Equipment failure		
10	24	0	56	0.66	1.36
11	24	0	52	0.58	1.81
12	24	0	37	0.39	1.91
13	24	0	37	0.67	1.17
14	24	0	55	0.76	1.13
15	24	0	37	0.55	1.14
16	24	0	19	0.78	1.94
17	24	5.6	38	0.62	2.6
18	24	trace	62	0.21	0.44
19	24	0	41	0.15	0.40
20	24	trace	-	1.4	0.26
21	24	0	45	0.57	0.36
22	24	trace	34	0.78	0.91
23	24	0	57	0.54	0.47
24	24	trace	49	0.62	0.68
25	24	8.1	106	0.38	1.04
26	24	7.4	Equipment failure		
27	24	trace	37	0.39	0.74
28	24	0	40	1.06	0.84
29	24	1.8	46	0.39	1.07
30	24	14.0	72	0.31	0.19
31	24	0	60	0.19	0.07
Nov 1	24	0	72	0.18	0.10
2	24	1.3	Equipment failure		
3	24	0.3	35	0.43	0.64
4	24	0	38	0.33	0.75
5	24	trace	45	0.60	0.45
6	24	0	88	0.85	0.52
7	24	0	30	0.33	0.46
8	24	0	87	0.63	0.71
9	24	0	82	0.86	0.44
10	24	0	68	0.97	0.57
11	24	41.0	Equipment failure		
12	24	0	66	0.34	0.32
13	24	0	53	0.20	0.42
14	24	0	51	0.28	0.31
15	24	0	50	0.57	0.19

(Table continues)

Table 2 (Continued)
Daily Atmospheric Radioactivity Measurements
at Yokosuka, Japan, 1957

(Filter: ACC Type-5 Collection usually ended at 1530 local time)					
Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity ($\mu\mu$c/cu m of air)		
			Radon	Thoron	Fission Products
Nov 16	24	2.0	131	0.83	0.29
17	24	17.3	60	0.42	0.29
18	24	8.6	51	0.31	0.35
19	24	0	66	0.49	0.37
20	24	0	40	0.50	0.30
21	24	0	38	0.41	0.45
22	24	0	67	0.07	0.45
23	24	0	42	0.55	0.32
24	24	0	36	1.04	0.26
25	24	0	44	0.66	0.20
26	24	12.4	94	0.93	0.39
27	24	2.8	15	0.31	0.45
28	24	0	-	0.54	0.11
29	24	0	34	0.21	0.11
30	24	0	32	0.32	0.23
Dec 1	24	0.5	46	0.52	0.24
2	24	0	42	0.64	0.04
3	24	0	30	0.46	0.09
4	24	trace	20	0.35	0.43
5	24	16.0	25	0.33	0.36
6	24	0	46	0.32	0.03
7	24	0	Equipment failure		
8	24	7.4	Equipment failure		
9	24	2.3	20	0.57	0.12
10	24	0	67	0.28	0.27
11	24	0	44	0.32	0.40
12	24	0	53	0.34	0.60
13	24	5.4	115	0.14	0.51
14	24	0	60	0.12	0.10
15	24	trace	59	0.38	0.14
16	24	0	-	0.34	0.17
17	24	trace	97	0.48	0.18
18	24	7.1	50	0.33	0.17
19	24	0	44	0.16	0.97
20	24	0	50	0.30	0.19
21	24	0	-	0.43	0.09
22	24	0	39	0.31	0.05
23	24	0	98	0.48	0.17
24	24	0	28	0.33	0.09
25	24	0	44	0.47	0.24
26	24	15.5	71	0.40	0.29
27	24	1.5	6	0.29	0.22
28	24	trace	39	0.32	0.12
29	24	0	48	0.35	0.50
30	24	0	40	0.44	0.11
31	24	0	Equipment failure		

Table 3
Some Daily Atmospheric Radioactivity Measurements at Rio de Janeiro, Brazil, 1957

(Filter: TFA 2133 Collection usually ended at 1550 local time)					
Collection Ending	Time of Collection (hr)	Rainfall (mm)	Radioactivity ($\mu\mu$c/cu m of air)		
			Radon	Thoron	Fission Products
June 26	11.8	0	260	7.7	0.14
27	11.8	0	240	6.4	0.03
28	11.8	0	270	6.8	0.12
July 2	11.8	0	170	9.9	0.63
12	12.3	0	110	3.4	0.06
16	11.8	0	140	4.3	0.05
17	11.8	0	440	10.0	0.04
18	23.8	3.8	340	6.1	0.26
19	11.8	0	150	9.0	0.90
23	11.8	4.0	29	3.1	0
24	11.8	0	120	4.0	0
25	11.8	6.4	210	5.6	0.12
26	24.0	0	120	3.6	0.15
Aug 1	12.8	0	123	4.9	0.22
2	12.8	0	15	1.8	0.11
6	13.0	0	45	4.2	0.09
7	12.8	0	70	3.8	0.41
8	12.8	0	97	5.2	0.27
9	12.8	0	180	6.7	0.08
15	12.8	0.9	31	2.3	0.19
16	12.8	0	50	2.3	0.18
20	12.8	0	128	4.3	0.09
21	12.8	0	136	8.5	0.35
22	12.8	1.5	18	1.6	0.04
23	12.8	0	7	1.7	0.11
27	12.8	0	90	4.0	0.34
28	12.8	0	107	5.5	0.12
29	15.8	0	126	9.3	0.23

Table 4
Geographical Distribution of Atmospheric Radioactivity During 1957

Location	Activity ($\mu\mu$c/cu m)		
	Radon	Thoron	Fission Products
Washington, D.C.	172	2.3	2.1
Yokosuka, Japan	54	0.48	0.66
Wales, Alaska	17	0.14	0.31
Kodiak, Alaska	7.3	0.042	0.16
Little America, Antarctica	1.5	<0.01	0.019

Table 5
Announced Dates of Nuclear Test Explosions During 1957

Date	United States	United Kingdom	U.S.S.R.
January	-	-	19
February	-	-	-
March	-	-	8
April	-	-	3,6,10,12,16
May	28 (Nevada)	15,31 (Christmas Island)	-
June	2,5,18,24 (Nevada)	19 (Christmas Island)	-
July	5,15,19,24,25 (Nevada)	-	-
August	7,18,23,30 (Nevada)	-	22
September	2,6,8,14,16,19,23,28 (Nevada)	14,25 (Maralinga, Australia)	9,24
October	7 (Nevada)	9 (Maralinga, Australia)	6,10
November	-	8 (Christmas Island)	-
December	-	-	28 (Siberia)

Table 6
Analyses of High-Volume Air-Filter Samples for Some Minor Natural Radioactive Constituents*

Collection Site	Collection Date (1957)	Volume (cu m)	Concentration of Isotope					
			(d/m per cu m of air)			(atoms per cu m of air)		
			Be-7	Pb-210	Po-210	Be-7	Pb-210	Po-210
Washington, D.C.	May 28	4.86×10^4	3.7×10^{-2}	1.4×10^{-2}	1.5×10^{-3}	4.2×10^3	2.3×10^5	4.4×10^2
	June 17	4.44×10^4	5.3×10^{-2}	3.2×10^{-2}	5.0×10^{-3}	6.0×10^3	5.3×10^5	1.4×10^3
	June 27	5.33×10^4	5.8×10^{-2}	6.1×10^{-2}	1.4×10^{-3}	6.6×10^3	1.0×10^5	4.1×10^2
	July 15	4.44×10^4	5.8×10^{-2}	1.1×10^{-2}	1.5×10^{-3}	6.6×10^3	1.9×10^5	4.4×10^2
Yokosuka, Japan	June 17	5.8×10^4	5.5×10^{-3}	3.2×10^{-2}	5.5×10^{-4}	6.2×10^2	5.3×10^5	1.6×10^2
	July 15	5.43×10^4	9.8×10^{-3}	2.9×10^{-2}	1.5×10^{-3}	1.1×10^3	4.8×10^5	4.4×10^2

*These analyses were performed by Messrs. Paul R. Gustafson and Donald Brath.

ATMOSPHERIC RADIOACTIVITY STUDIES AT THE U.S. NAVAL RESEARCH LABORATORY

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Historically, the U.S. Naval Research Laboratory has had a direct interest and an important part in developments in the field of atomic energy since the initial discovery of the fission process. We will report here on one aspect of that interest, the concentration of fission products in the atmosphere as measured at ground level. This work is presently being done as part of the U.S.-IGY program, and the results are reported to the United Nations and to the IGY World Data Centers. Because this meeting is concerned with the history of the general subject under discussion, I will digress a moment or two from the factual data to tell you about the origin of our work.

Ten years ago, actually early in 1948, the observation was made that gamma counters located on the ground at various places in the Northern Hemisphere showed a marked increase in gamma count whenever rain fell. This indicated the possible use of rainfall as a scavenger for airborne radioactive matter. We knew that there had been some atomic bomb tests in the Pacific and suspected that the increase in count could be due to fission products, although the possibility existed that it could be due to the natural radioactivity always present in the atmosphere.

In order to determine specifically what the activity was due to, it was necessary to obtain rain water that had been collected during the early months of 1948. A source of such water was discovered in the Virgin Islands where the entire water supply comes from rain which is stored in large cisterns. In June 1948 one of us went to St. Thomas and treated 2500 gallons of the cistern water with aluminum hydroxide floc, which was returned to NRL for radiochemical analysis. Positive identification of the fission products Ce^{141}, Ce^{144}, and Y^{91} proved that the increase observed was due at least in part to fission products. A similar experiment using cistern water and plant material from Truk Atoll gave even higher fission product counts. Following this, experimental sites were set up in Washington, D.C., and Kodiak, Alaska, early in 1949, and routine rain water collections from roofs 1000 sq ft in area were flocced and the floc examined for fission products.

No fission products at all were found in the rain water from Kodiak, but trace amounts were found in the water collected at NRL in Washington. We naturally suspected Oak Ridge to be the source but decided to check our roof surface to see if it possibly were contaminated. Our Public Works people were certain then that all scientists were crazy when we requested a crew of laborers to scrub down our roof with brushes and to save the washings for us. However, from these washings were isolated thousands of counts per minute of the natural radioactive materials RaD, RaE, and RaF (Po^{210}) together with a few hundred counts per minute of cerium and yttrium activity. From the small amount of Ce^{141} present it was deduced that the source of this material was the atomic tests held the previous year. We immediately had a new aluminum roof installed and began collecting rain water free of fission products. All during the spring and summer of 1949 no fission products were found in the rain, but in September of that year thousands of counts per minute of separated products were found in the water from Kodiak, and hundreds of counts per minute in the water from Washington (Table 1). These numerical values are meaningless because our

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NOTE: This report was prepared for oral presentation at the symposium "Inorganic Chemists in the Nuclear Age" at the national meeting of the American Chemical Society, Chicago, Illinois, September 8, 1958. It is reproduced here because of many requests for copies owing to the current popular appeal of the subject matter.

chemical recovery, which was occasionally very poor, is not shown. However, the magnitude of the activity we isolated is evident.

Table 1
Radioactivity of Rain Collections*

Rains	Ce	Y†	Ru	Ba	Ag
Washington, D.C.					
16-18 June 1949	0	0	–	–	–
15-18 July 1949	0	0	–	–	–
3 Aug 1949	0	0	0	–	–
12-15 Aug 1949	0	0	–	–	–
28 Aug 1949	0	0	–	–	–
13 Sept 1949	60	600	180	300	–
Kodiak, Alaska					
Apr 1949	0	0	0	–	–
16-31 May 1949	0	0	0	–	–
3-13 June 1949	0	0	0	–	–
20 June-10 July 1949	0	0	0	–	–
8-12 Sept 1949	3900	12,700	8700	10,000	700
13-16 Sept 1949	4600	25,000	5800	13,000	–

*Counts per minute at approximately 20-percent geometry (not corrected for chemical recovery or decay).

†Contains Y and rare earths other than Ce.

While this work was going on, nonchemical studies were being carried out to perfect a means of detecting low concentrations of fission products in the presence of the relatively high levels of natural radioactive material in the air. A physical method of analysis was soon devised wherein particulate matter is collected from the air on efficient filters of small area, which permits the identification of gross fission products through their effect on the rate of decay of the collected radioactivity (1).

This NRL atmospheric radioactivity monitor equipment was designed for estimating the natural radioactive isotopes radon and thoron through measurements of their short-lived decay products, and determining the gross long-lived β emitters in the air. The decay schemes of these materials are as follows:

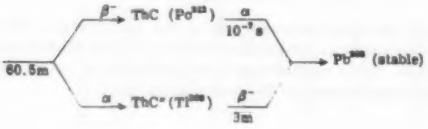
Radon Series

a. $Rn^{222} \xrightarrow[3.8d]{\alpha} RaA\ (Po^{218}) \xrightarrow[3m]{\alpha} RaB\ (Pb^{214}) \xrightarrow[26.8m]{\beta^-} RaC\ (Bi^{214}) \xrightarrow[19.7m]{\beta^-} RaC'\ (Po^{214}) \xrightarrow[10^{-4}s]{\alpha} RaD$

b. $RaD\ (Pb^{210}) \xrightarrow[23y]{\beta^-} RaE\ (Bi^{210}) \xrightarrow[5d]{\beta^-} RaF\ (Po^{210}) \xrightarrow[140d]{\alpha} Pb^{206}\ (stable)$

Thoron Series

$Tn\ (Rn^{220}) \xrightarrow[54s]{\alpha} ThA\ (Po^{216}) \xrightarrow[0.2s]{\alpha} ThB\ (Pb^{212}) \xrightarrow[10.6h]{\beta^-} ThC\ (Bi^{212})$



The equipment employed is shown in Fig. 1. Air is drawn through a stack from outside and passed through an efficient filter which effectively removes all particles greater than 0.3 μ in diameter. A GM tube mounted directly above the filter gives an indication of the buildup of radioactivity on the filter. After 24 hours operation, during which 900 to 1200 cubic meters of air pass through the filter, the filter is transferred to a lead jug containing a similar GM tube and its decay followed for the next 16 hours. Figure 2 shows a typical trace obtained during a collection. The rapid buildup is due to collection of the 26-minute daughter of radon (RaB). This activity is normally so high and so variable that it is generally impossible to identify the time of influx of fresh fission products into the area. Figure 3 shows typical decay curves of such collections, one consisting purely of natural products and the other containing natural materials plus fission products (20 percent). After 5 hours, the contribution of the radon daughters is negligible. From the ratio of the 6-hour to the 16-hour count or from the apparent half-life of the mixture of longer lived β emitters, the contribution of both gross fission products and thoron decay products to the total activity may be calculated.

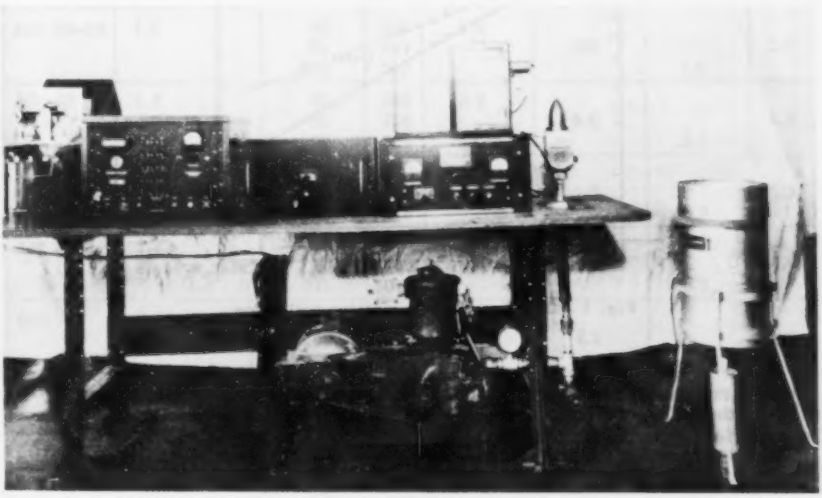


Fig. 1 - Monitor equipment

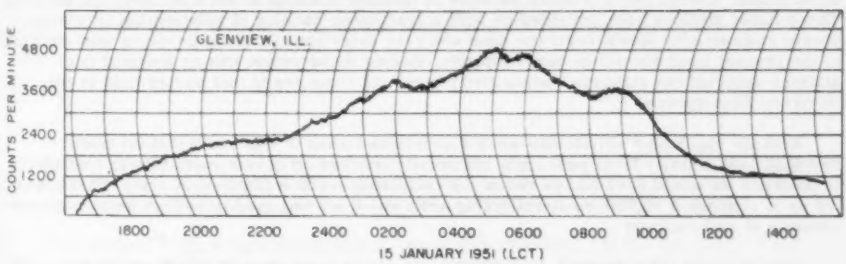


Fig. 2 - Recording of activity buildup during collection

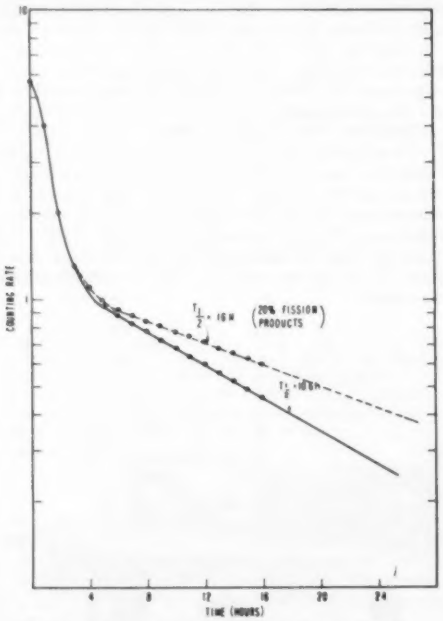


Fig. 3 - Decay curve of a monitor collection

A point that should be mentioned is that this early work on the detection of fission products in the air was initiated by people at NRL and carried out without access to classified material. It could have been done by anyone who had access to the Smythe report or to the 1946 Journal of the American Chemical Society report entitled "Nuclei Found in Fission," which was issued by the Plutonium Project of the Manhattan Project.

The years following the initial successes of this work in 1949 were spent in improving our air monitoring procedures, working up more comprehensive procedures for chemical separations, and operating a small network of monitor stations at various naval installations. These latter stations have provided us with a continuous backlog of information on atmospheric radioactivity levels from the time when the detection of fission products was exciting to the present time when it is commonplace. During these years, one or more of our stations detected the airborne radioactivity resulting from every test series held in the Northern Hemisphere.

Routine rain water collections were discontinued when it was found that so much residual radioactivity from past tests continually leached off of our roofs that to continue in business we would have had to renew the collecting surface after every test. This also led us to abandon a 10,000-sq-ft collecting area which we had used to collect more massive amounts of radioactivity.

Before leaving this subject, I would like to present some data (Table 2) on the naturally occurring radioisotope RaE (Bi^{210}) and its relation to rainfall (2). RaE is the 5-day daughter

of the 22-year RaD (Pb^{210}), which itself results from the decay of the radon in the air. The rains appear to vary in their ability to cleanse the lower atmosphere as is indicated by the high activity levels sometimes encountered in the last part of the rain. The lower efficiency of some of these may be due in part to the movement of "unclean" air into the area while the rain is falling. In general, it is apparent that the first part of the rain contains a higher concentration of RaE (or RaD). The dust content of this fraction is also high, but the RaE content has been found to be independent of the dust level.

Table 2
Distribution of RaE (Bi^{210}) Activity Among Rain Water Fractions Collected at NRL

Date Collected (1950)	Rainfall (in.)	Volume of Fraction† (gal)	β Activity of Separated Bismuth Carrier (RaE)*				
			c/m	c/m gal			
				Fraction A	Fraction B	Fraction C	Total
July 15-16	1.5	40	236	5.9			
		55	123		2.2		1.7
		300	308			1.0	
July 20	1.4	40	230	5.7			
		60	216		3.6		1.9
		300	324			1.1	
Aug 19	4.08 (Continuous)	40	170	4.3			
		60	108		1.8		1.3
		275	218			0.8	
Aug 23	1.35 (2-hour rain)	40	276	6.9			
		60	176		2.9		4.0
		275	1064			3.9	
Sept 21	0.86	40	133	3.3			
		60	174		2.9		3.0
		275	825			3.0	
Oct 8-9	0.54	40	128	3.2			
		60	95		1.6		1.2
		275	226			0.8	
Oct 23	1.86	40	200	5.8			
		60	189		3.2		2.0
		275	340			1.2	
Average for 12 collections June-Nov 1950				4.7	2.2	1.5	2.0

*Corrected for decay and yield; counted at approximately 10-percent geometry.

†Runoff from 1000-sq-ft roof diverted successively into tanks A, B, and C.

A study of this type, combined with air-filter measurements of RaD and of the short-lived radon daughters, led to the conclusion a number of years ago that rain is the primary agent for removal of long-lived radioactivity from the air and, further, that the "mean life" of natural radioactivity in the air due to nonradioactive loss is about 15 days (3).

The present NRL program consists of two major projects: (a) the operation of air monitor stations of the type we have had in use for the past 10 years and (b) the measurement

of the latitudinal variation of the radioactivity of the air at ground level along the 80th meridian (west). This work is a part of the IGY program on Atmospheric Nuclear Radiation.

In Table 3 is presented the distribution of fission products and of the major natural radioactive isotopes in the air at several distinct geographical locations during 1957. These values were calculated from data obtained with the NRL air monitor equipment described previously. Identical equipment is presently in operation also at San Francisco, at Rio de Janeiro, and at Chacaltaya, Bolivia, at the high-altitude cosmic-ray laboratory.

Table 3
Geographical Distribution of Atmospheric Radioactivity During 1957

	Activity (micromicrocuries per cubic meter*)		
	Radon	Thoron	Fission Products
Washington, D.C.	172	2.3	2.1
Yokosuka, Japan	54	0.48	0.66
Wales, Alaska	16.7	0.14	0.31
Kodiak, Alaska	7.3	0.042	0.16
Little America	1.5	<0.01	0.019

*1 $\mu\mu$ curie/m^3 = 10^{-18} curies/cc

Figures 4, 5, and 6 show the monthly variations in the natural and fission product activities at Washington, Kodiak, and Yokosuka during 1957. The large increase in gross fission products at Washington during July through September is due to our extensive series of nuclear tests in Nevada (Plumbbob). The maximum daily reading during the month is also presented on this graph and shows that even the peak fission product activity is much below the average radon level. Kodiak showed little response to these Nevada tests, but the fission product level increased markedly after the USSR tests of August through October 1957. At Yokosuka there were two peaks of activity that corresponded to the two series of USSR tests with a definite lull during the period of our Nevada tests. In every case the average radon content of the air was 50 to 100 times that of the gross fission product level. In Fig. 7 is shown a comparison of the variations in fission product levels at the different sites during 1957.

The second phase of our work, which is carried out as part of the United States contribution to the Nuclear Radiation program of the IGY, consists of the daily exposure at each of the collecting sites of the most effjcient filters available. A simple air pump draws air through a 8-inch-diameter filter paper at about 30 cubic feet per minute (1200 cubic meters per day). Local personnel at the cooperating site change the filters and return them to NRL via air. Here they are ashed at 650°C, compressed into 1-inch-diameter disks, and counted under a thin-window GM tube 14 days after collection. Sufficient counts are obtained on each sample to give a ±5-percent error at the 95-percent confidence level. Counting rates are converted to disintegration rates by the use of a factor derived from the counting rate of a radioactive standard mounted in an identical manner. The gross fission products are assumed to have an effective β energy of 1 Mev.

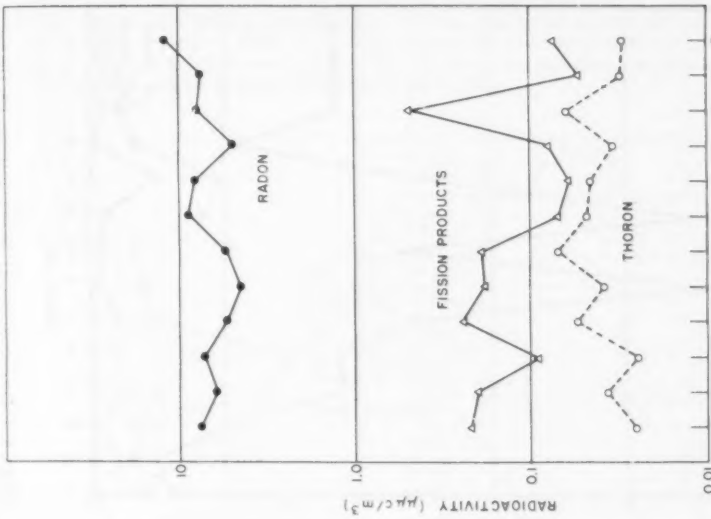


Fig. 5 - Monthly averages of atmospheric radioactivity levels at Kodiak during 1957

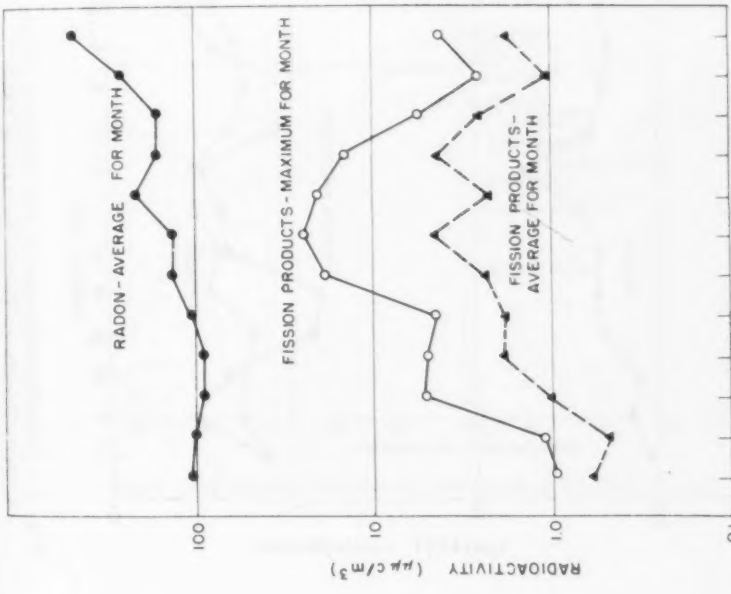


Fig. 4 - Atmospheric radioactivity levels at Washington, D.C., during 1957

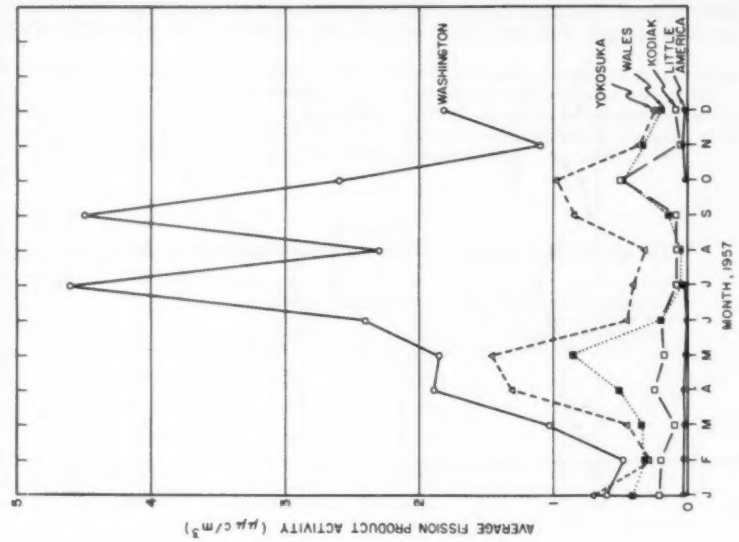


Fig. 7 - Geographical distribution of fission products in the air during 1957

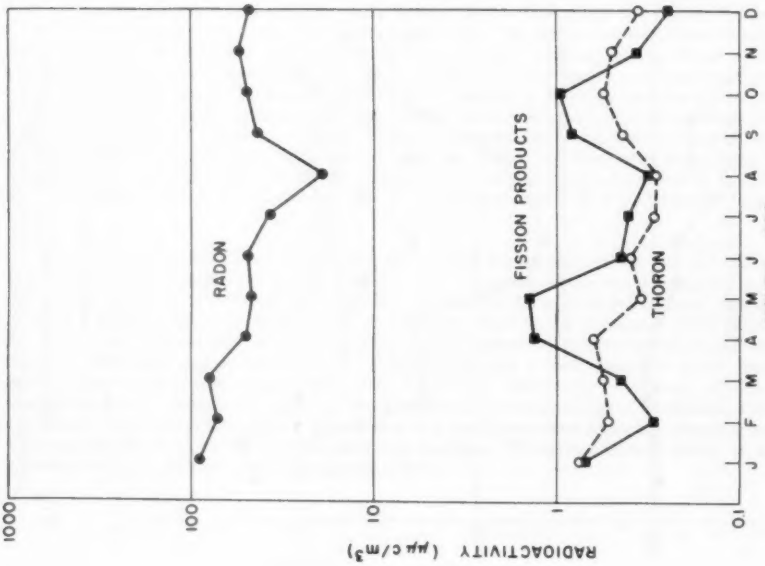


Fig. 6 - Monthly averages of atmospheric radioactivity levels at Yokosuka during 1957

Currently our complete network of 21 stations is in operation (Fig. 8). Some of these collecting stations have been in operation for over two years, though this IGY program itself officially started in January 1958. Other similar stations are operated by NRL as part of this IGY program at Pearl Harbor and atop Mauna Loa in the Hawaiian Islands, at Subic Bay in the Philippines, and on Drifting Station A in the Arctic.

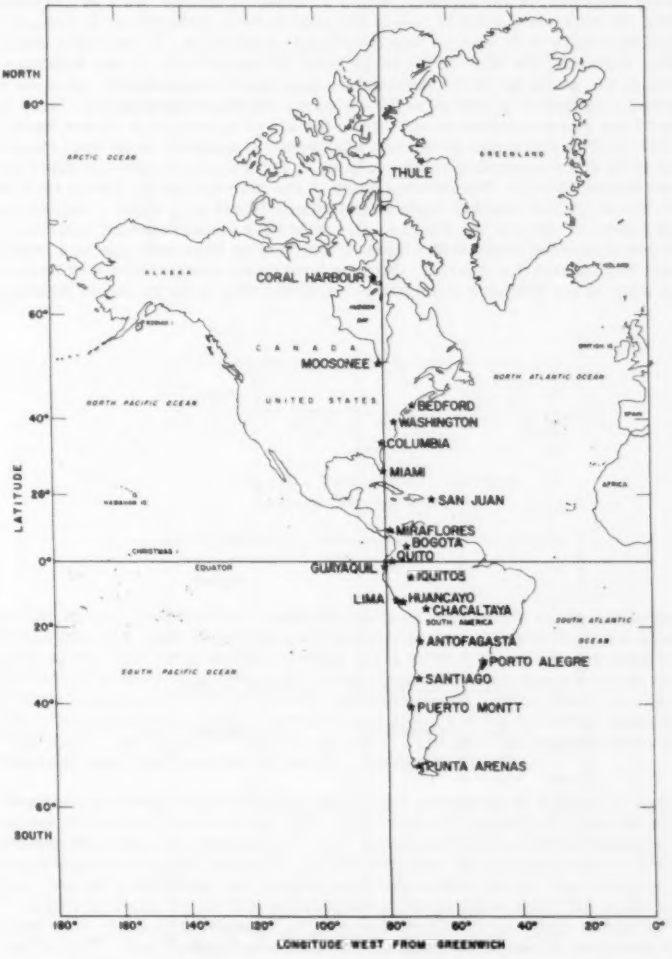


Fig. 8 - Atmospheric radioactivity stations along the 80th meridian

Fig. 6 - Monthly averages of atmospheric radioactivity levels at Yokosuka during 1957

Fig. 7 - Geographical distribution of fission products in the air during 1957

"Radioactivity profiles" showing the monthly average air concentration of fission products as a function of the latitude of the collection station during the periods July through December 1957 and January through June 1958 are shown in Figs. 9 and 10. In Fig. 9 the radioactivity from Nevada tests is seen to be concentrated primarily in the region between 20°N and 40°N and to dissipate rapidly through deposition, dilution, and decay following cessation of the tests in early October 1957. There are some fluctuations in radioactivity levels below the Equator, which were due to British tests at Christmas Island. In Fig. 10 the fission product levels are seen to be a little higher in January and February than they were in November and December, possibly due to the USSR test of December 28. Following the start of the large USSR series of tests in late February 1958, activity levels in the whole Northern Hemisphere increased tremendously. In spite of this high concentration of fission products in the air of the Northern Hemisphere, there was no indication of any gross transfer of activity to the air of the Southern Hemisphere. The fission product activity there was shown by radiochemical analyses to be due primarily to more ancient tests and presumably resulted, in part, from the stratospheric deposition of old fission (or fusion) debris. The decided hump in the activity profile during May and June is again due to British nuclear tests at Christmas Island with some contribution from our Hardtack series of tests in the Pacific. Our July 1958 measurements, however, showed a large increase in activity south of the Equator which must have been due to a massive transfer of activity across this barrier. For the first time, concentrations of fission products at some sites in the Southern Hemisphere exceeded that in the Northern Hemisphere.

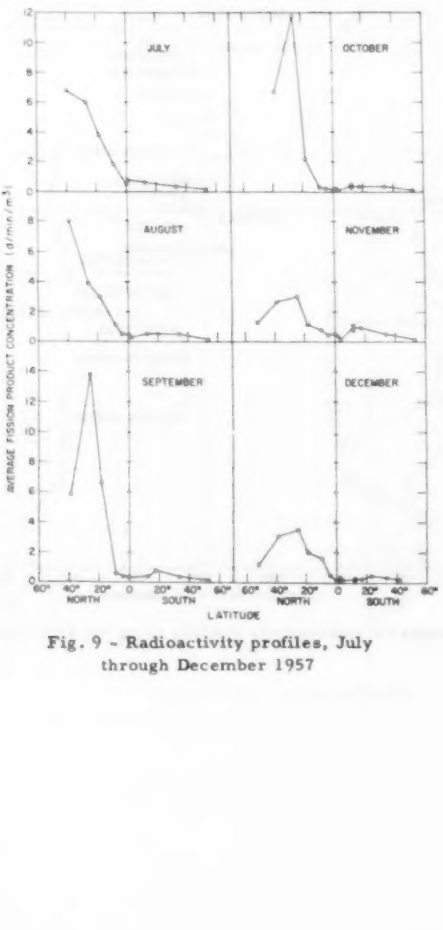


Fig. 9 - Radioactivity profiles, July through December 1957

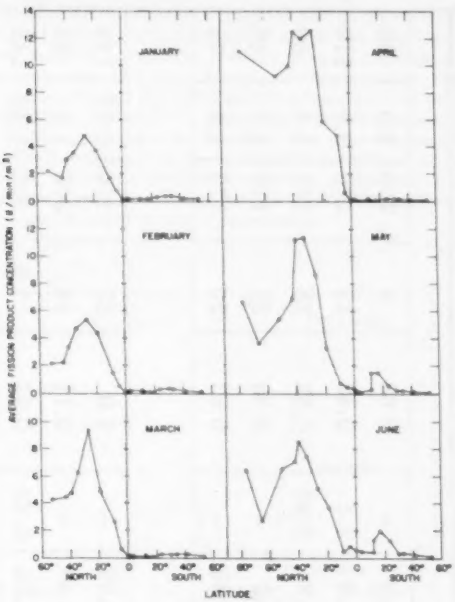


Fig. 10 - Radioactivity profiles, January through June 1958

So far in this presentation chemistry has been kept rather in the background, but actually it has played a most important part throughout this entire study. A major portion of our time on this IGY program is presently being spent on the radiochemical analysis of monthly samples from each of the collecting sites. The samples are made up from the ash of the daily filters, and, since these are asbestos-based papers, there is a considerable quantity of material to process. Carriers are added and the following isotopes separated: $Sr^{89,90}(Y^{90})$, Y^{91}, Cs^{137}, $Ce^{141,144}(Pr^{144})$, and Pb^{210}. The Pb^{210} is included since it represents the principal long-lived natural radioactive isotope in the air.

Some preliminary radiochemical results are presented in Table 4 in terms of disintegrations per minute per hundred cubic meters of air corrected to sea-level density. It is apparent that both the gross activity and the activity due to the individual fission products are much higher in the Northern than in the Southern Hemisphere during December 1957. Further, the air over South America is relatively richer in the long-lived isotope Sr^{90} (and Cs^{137}), which is shown by the higher fraction of the gross activity due to Sr^{90} and by the apparent ages of the collections as determined from activity ratios of the pairs Sr^{89}/Sr^{90} and Ce^{141}/Ce^{144}. The disagreement between the apparent ages, as determined from these or other activity ratios, indicates that activity of different ages is present; that is, both fresh and old debris are present.

Table 4
Radiochemical Analyses of Air-Filter Samples Collected During December 1957

Station	Rainfall		Radioactivity (disintegrations per minute per 100 standard cubic meters*)								Sr^{90}/Gross	Sr^{89}/Sr^{90}		Ce^{141}/Ce^{144}	
	Days	mm	Gross	Ce^{141}	Sr^{89}	Y^{91}	Ce^{144}	Sr^{90}	Cs^{137}	Pb^{210}	Percent	Ratio	Age†	Ratio	Age†
Northern Hemisphere															
Moosonee	18	59	120	28	7.4	19	9.3	0.82	1.3	–	0.68	9	250	3.0	50
Washington	12	133	310	24	24	46	27	1.3	2.6	2.1	0.42	18	190	0.9	110
Miami	10	63	340	50	29	65	31	1.1	2.2	0.90	0.32	28	155	1.6	80
Miraflores	5	7	160	22	14	23	8.9	0.61	1.2	–	0.38	22	170	2.5	60
Bogota	5	30	57	10.4	6.1	9.6	5.6	0.30	0.49	–	0.53	20	175	1.9	75
Southern Hemisphere															
Lima	4	4	23	2.0	5.3	3.2	2.6	0.24	0.59	–	1.0	22	170	0.77	115
Huancayo	21	65	28	2.2	3.1	4.1	1.5	0.20	0.49	–	0.71	16	200	1.5	85
Chacaltaya	3	10	38	1.2	1.8	3.6	2.5	0.37	0.88	0.92	0.97	4.9	300	0.48	145
Antofagasta	0	0	47	2.5	2.2	4.2	4.5	0.51	1.0	0.48	1.1	4	>300	0.56	135
Santiago	–	–	32	5.3	2.9	12	4.0	0.54	1.4	–	1.7	5.4	270	1.3	90

*Corrected for decay to midpoint of collecting period.

†Age in days; assumes equal yields of these elements in fission process.

Some information indicating the change in relative age of the debris with time is presented graphically in Fig. 11. Here the percentage of the gross activity which is due to Sr^{90} is plotted for a series of monthly collections made at several sites along the 80th meridian. At the Northern Hemisphere sites (Panama, Miami, and Washington), the relative concentration of Sr^{90} was low during August through October because of the influx of freshly fissioned material from Nevada. The rapid increase after October is due in part to the rapid decay of the shorter lived fission products. However, the rate of rise is too high to be accounted for by decay alone and must be due to important additions of older fission products to the air masses sampled. Since the average lifetime of particulate matter in the lower atmosphere is less than one month because of natural deposition processes, the source of this excess long-lived material must be the stratosphere.

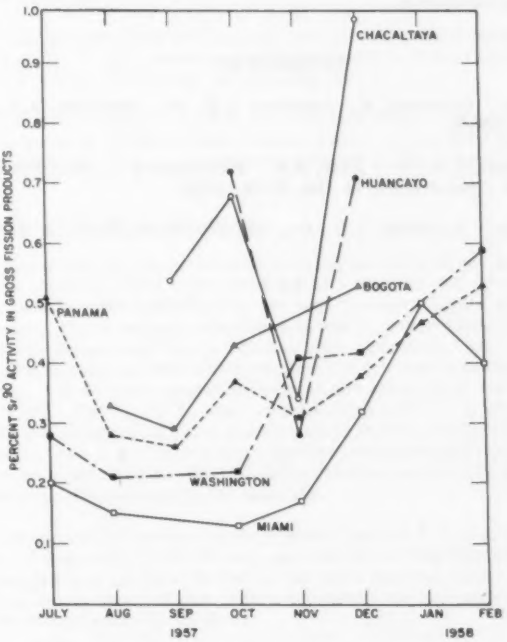


Fig. 11 - Variation in the Sr^{90} contribution to the gross fission product activity of the air

In the absence of new nuclear tests, the percentage of Sr^{90} in the gross fission products should gradually increase as the shorter lived fission products die out. Eventually, the rate of decrease of the concentration of Sr^{90} in the air will be a measure of the rate of decrease of the concentration of Sr^{90} in the stratosphere. Thus a direct measure of the storage time of this material in the stratosphere can result.

†Age in days; assumes equal yields of these elements in fission process.

Curves of the Sr^{90} contribution to the gross fission product activity for two sites south of the Equator are also shown in Fig. 11. The high relative amounts of Sr^{90} indicate that the debris here are fairly old.' The low Ce^{141} and Y^{91} values from the previous table confirm this. A decided dip in the percentage of Sr^{90} occurred in November following British tests in Australia (September through October) and at Christmas Island (November 8). The ratio increased to its previous high value in December, indicating a fast washout of the fresh activity. This fast recovery of the atmosphere from such contamination was noted a number of years ago at our monitor stations in the Northern Hemisphere (1), but we see it no longer there.

It is out hope that information of the type presented here on the radioactivity of the air will serve, eventually, to help in the prediction of fallout, to determine mixing rates across the equatorial barrier in the stratosphere, and to determine the magnitude and residence time of Sr^{90} in the stratosphere.

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RADIOCHEMICAL ANALYSES OF AIR-FILTER SAMPLES COLLECTED DURING 1957

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INTRODUCTION

The U.S. Naval Research Laboratory has undertaken a program of measurement of the radioactivity of the air in cooperation with the U.S. Weather Bureau, the U.S. Atomic Energy Commission, the U.S. Air Force, and organizations in Canada, Colombia, Ecuador, Peru, Bolivia, Chile, and Brazil as part of the International Geophysical Year Program on Atmospheric Nuclear Radiation (1-3).

Daily measurements are made of the gross activity collected at each of the cooperating collecting sites (Fig. 1). These results are reported monthly to participants in this program and to the IGY World Data Center at Asheville, N.C.

An integral and most important part of this program involves the radiochemical analyses of composite monthly samples from most of the collecting sites for a number of high-yield fission elements, using a procedure developed at this Laboratory (4).

COLLECTION AND ANALYSIS OF SAMPLES

Radioactive materials are collected daily at all of the sites along the 80th meridian by the use of small air-filter units which draw air at a uniform rate of approximately 30 cubic feet per minute (1200 cubic meters per day) through a highly efficient filter, 8 inches in diameter. These samples are ashed at 650°C, compressed to a small disk, and the gross activity determined on the 14th day after collection. After being counted, a monthly composite sample for radiochemical analysis is made from the daily collections from each location. All of these composite samples are analyzed at this Laboratory for Sr^{89}, Sr^{90}, Y^{91}, Cs^{137}, Ce^{141}, Ce^{144}, and occasionally for Pb^{210} (a naturally occurring radioisotope) with the exception of those samples from Puerto Montt, Chile; Porto Alegre, Brazil; Iquitos, Peru; San Juan, Puerto Rico; Bedford, Massachusetts; and Thule, Greenland; which are forwarded to the U.S. Air Force Cambridge Research Center (Geophysics Research Directorate), Bedford, Massachusetts, for analysis.

Week-long sample collections are made at Pearl Harbor and atop Mauna Loa in the Hawaiian Islands, at Subic Bay in the Philippines, and at Drifting Station A in the Arctic. The equipment employed is identical to that at the other stations except that a filter 13-1/2 x 15-1/2 inches is used. These papers are ashed and the gross activity determined and then analyzed radiochemically as above.

RELIABILITY OF DATA

A number of the air-filter units were compared for both the free-air capacity and flow rate through a standard filter of the type employed (Army Chemical Corps Type 6). All units agreed within ±5 percent. The flow rate with any one unit should show considerably less variation than this, since the pump is operated under the same conditions at all times; that is, the filters have been constructed so as to have a definite resistance

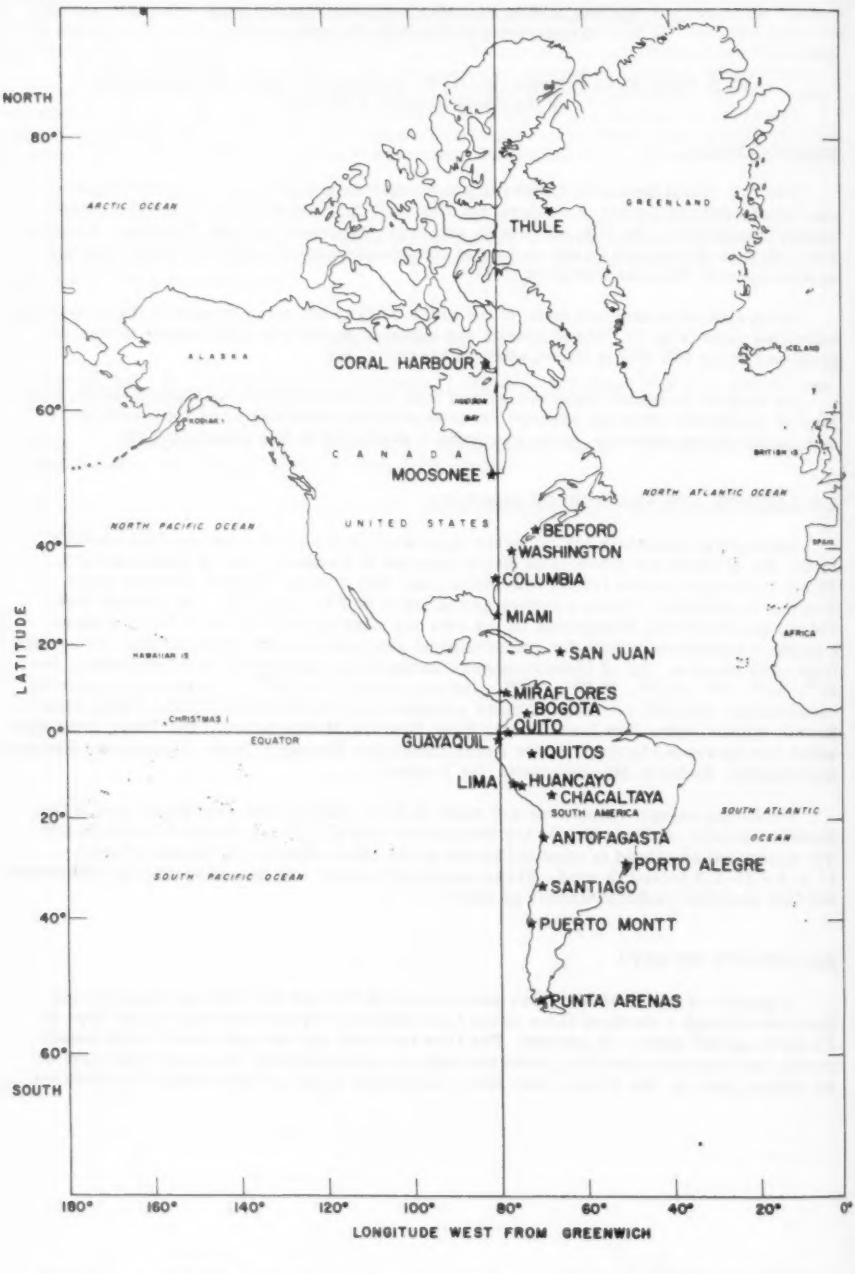

Fig. 1 - Atmospheric radioactivity stations along the 80th meridian

to air flow at velocities comparable to those employed here, the filters are sufficiently large that no appreciable drop in air flow occurs because of clogging up of the filter during the collection period, and the pumps are driven by synchronous motors that are not sensitive to reasonable variations in the voltage of the electrical supply. The effect of reduced pressure at high altitudes on the efficiency of the pump has also been taken into account.

The counting error for most samples has been kept below ±5 percent at the 95-percent confidence level. For a number of the radiochemically separated samples the counting error is much less than this, since relatively high activities were encountered. Special care was taken to keep the error in the Sr^{90} determination as small as possible (Appendix A).

Counting rates are converted to disintegration rates by the use of factors derived from counting similar samples of known disintegration rates under the same conditions. For example, Y^{90} milked from a National Bureau of Standards Sr^{90} (Y^{90}) standard is used to calibrate the Y^{90} counters. The error may be relatively large in the case of the total or gross β count of the samples since the mixed fission products have been assumed to have an average β energy of 1 Mev. Low energy β's are thus discounted by their high absorption in the filter ash. However, for the chemically isolated activities, the comparison is performed with standard isotopes of similar β energy so that this error is small.

Somewhat larger errors are obtained for the Sr^{89} and Ce^{141} determinations because of the necessity of obtaining these activities by difference. Sr^{89} is determined from the Sr^{89}, Sr^{90} count by correcting for the Sr^{90}, which is determined by milking Y^{90}; Ce^{141} is determined from the total Ce^{141}, $Ce^{144}(Pr^{144})$ count by correcting for the presence of the $Ce^{144}(Pr^{144})$ activity. In these cases the counting error is generally of the order of ±10 percent at the 95-percent confidence level. In samples of relatively low Sr^{89} and Ce^{141} activity, that is, in "old" samples, this error may be much greater.

RESULTS AND DISCUSSION

Radiochemical Analyses

The results obtained by radiochemical analysis of composite monthly air-filter collections from the various stations during 1957 are presented in Table 1. Activities are expressed in disintegrations per minute per 100 standard cubic meters of air (sea-level density) corrected for radioactive decay to the mid-date of the collection period. The ratios of Sr^{90} to gross β activity and Sr^{89} to Sr^{90} activity are presented to indicate roughly the relative ages of the mixed fission debris. High Sr^{90}/gross β values indicate old debris, while high Sr^{89}/Sr^{90} ratios indicate young debris.

The ratio of Cs^{137}/Sr^{90} activity is also included because of the similarity of Cs^{137} and Sr^{90} in yield and half-life. Generally, this ratio is around 2.0 but varies from a high of 4.3 to a low of 0.90. There is no obvious explanation for this variation. The extremely low values (0.5) for the Cs^{137}/Sr^{90} ratio reported by Stewart et al. (5) for Melbourne, Australia, and Gibraltar rain collections have not been found in any of these air-filter collections. The selective removal of Sr^{90} relative to Cs^{137} in rainfall as postulated by Storebo (6) could account for the highest values. However, the consistent appearance of values near 2, regardless of latitude or longitude, makes it seem likely that this number represents the relative concentrations of these isotopes in the source material.

Time Variation of Long-Lived Activity in the Air

Monthly variations in the activity of several long-lived radioisotopes in the air are plotted in Figs. 2 and 3 for those stations where data are available for 4 months or more.

Table 1
Radiochemical Analyses of Composite Monthly Air-Filter Collections

Month	Rainfall		Activity (disintegrations/minute per 100 standard cubic meters of air)										
	Days	mm	Gross β	Ce^{141}*	Sr^{89}*	Y^{91}*	Ce^{144}	Sr^{90}	Cs^{137}	Pb^{210}	Sr^{90}/Gross β	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Moosonee, Ontario - Lat. 51°16′N Long. 80°30′W Elev. 10 m													
Nov. 1957	18	182	130	25	7.8	19	8.5	0.48	0.92	0.81	0.0037	15	1.9
Dec. 1957	18	59	120	28	7.4	19	9.3	0.82	1.3	-	0.0068	9.0	1.6
Washington, D. C. - Lat. 38°50′N Long. 76°57′W Elev. 88 m													
May 1957	4	22	400	59	39	47	31	1.8	6.5	3.3	0.0045	22	3.6
June 1957	11	76	500	110	42	62	29	1.8	6.2	2.7	0.0036	23	3.4
July 1957	5	24	670	100	45	45	33	1.9	5.4	2.7	0.0028	23	2.8
Aug. 1957	5	59	800	89	44	71	31	1.7	6.1	-	0.0021	26	3.6
Oct. 1957	6	84	670	140	64	76	25	1.5	3.8	3.2	0.0022	41	2.5
Nov. 1957	14	63	270	42	19	36	19	1.1	1.4	1.3	0.0041	18	1.3
Dec. 1957	12	133	310	24	24	46	27	1.3	2.6	2.1	0.0042	18	2.0
Miami, Florida - Lat. 25°49′N Long. 80°17′W Elev. 4 m													
July 1957	15	276	590	58	49	56	24	1.2	2.4	1.9	0.0020	40	2.0
Aug. 1957	17	339	380	55	29	45	14	0.57	1.0	-	0.0015	52	1.8
Oct. 1957	11	184	1170	220	78	100	36	1.5	2.2	1.7	0.0013	51	1.5
Nov. 1957	3	47	300	32	7.9	40	21	0.51	1.7	0.47	0.0017	15	3.3
Dec. 1957	10	83	340	50	29	65	31	1.1	2.2	0.90	0.0032	28	2.0
San Juan, Puerto Rico - Lat. 18°26′N Long. 66°00′W Elev. 21 m													
July 1957	14	130	380	95	30	84	28	1.1	2.3	0.90	0.0029	27	2.1
Aug. 1957	19	184	300	57	31	44	14	0.65	1.5	-	0.0022	48	2.3
Sept. 1957	19	112	680	140	45	55	17	0.73	1.3	-	0.0011	62	1.8
Oct. 1957	17	202	420	33	19	23	9.0	0.47	0.87	0.57	0.0021	39	1.9
Nov. 1957	21	130	110	13	8.1	16	7.8	0.71	0.64	0.09	0.0065	11	0.90
Miraflores, Panama Canal Zone - Lat. 9°00′N Long. 79°35′W Elev. 10 m													
July 1957	19	202	180	17	12	23	8.7	0.92	1.3	2.5	0.0051	13	1.4
Aug. 1957	22	301	110	13	11	15	7.1	0.31	0.71	-	0.0028	35	2.3
Sept. 1957	15	301	50	10	2.5	8.0	2.7	0.13	0.23	-	0.0026	19	1.8
Oct. 1957	19	372	25	0.63	1.9	2.9	1.6	0.092	0.13	-	0.0037	20	1.4
Nov. 1957	22	164	78	12	3.6	3.8	1.5	0.24	0.63	0.62	0.0031	15	2.6
Dec. 1957	5	7	180	22	14	23	8.9	0.61	1.2	-	0.0038	22	2.0
Bogota, Colombia - Lat. 4°37′N Long. 74°04′W Elev. 2640 m													
Aug. 1957	17	20	46	6.9	4.9	8.3	4.4	0.15	0.29	-	0.0033	33	2.0
Sept. 1957	10	34	49	4.2	4.0	6.4	3.1	0.14	0.31	-	0.0029	30	2.2
Oct. 1957	21	181	23	0.00	1.3	2.5	1.9	0.098	0.20	-	0.0043	13	2.0
Dec. 1957	5	30	57	10.4	6.1	9.6	5.6	0.30	0.49	-	0.0053	20	1.6
Quito, Ecuador - Lat. 0°08′S Long. 78°26′W Elev. 2818 m													
Sept. 1957	1	27	31	39	5.7	17	5.6	0.15	0.22	-	0.0048	38	1.5
Oct. 1957	4	15	12	1.0	0.82	1.8	1.3	0.066	0.27	0.69	0.0055	12	4.1
Nov. 1957	8	60	64	7.2	6.6	15	5.8	0.12	0.51	0.52	0.0019	55	4.3
Lima, Peru - Lat. 12°06′S Long. 77°01′W Elev. 134 m													
Dec. 1957	4	4	23	2.0	5.3	3.2	2.6	0.24	0.59	-	0.0100	22	2.5
Huancayo, Peru - Lat. 12°07′S Long. 75°20′W Elev. 3353 m													
Oct. 1957	13	74	32	0.00	2.8	5.1	3.9	0.23	0.53	-	0.0072	12	2.3
Nov. 1957	11	60	150	42	13	22	5.2	0.42	0.87	-	0.0028	31	2.1
Dec. 1957	21	65	28	2.2	3.1	4.1	1.5	0.20	0.49	-	0.0071	16	2.5

*Extrapolated to the middle of the collection period.

†Not Reported

(Table continues)

Table 1 (Continued)

Radiochemical Analyses of Composite Monthly Air-Filter Collections

Month	Rainfall		Activity (disintegrations/minute per 100 standard cubic meters of air)										
	Days	mm	Gross β	Ce^{141}*	Sr^{89}*	Y^{91}*	Ce^{144}	Sr^{90}	Cs^{137}	Pb^{210}	$Sr^{90}/Gross\ \beta$	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Chacaltaya, Bolivia - Lat. 17°10'S Long. 68°15'W Elev. 5220 m													
Sept. 1957	1	10	130	26	13	23	14	0.70	1.1	-	0.0054	18	1.6
Oct. 1957	7	25	53	4.9	4.3	7.6	5.1	0.36	0.86	-	0.0068	12	2.4
Nov. 1957	3	33	160	27	10	24	7.6	0.55	1.3	0.76	0.0034	19	2.4
Dec. 1957	3	10	38	1.2	2.3	3.6	2.5	0.33	0.88	0.92	0.0087	6.9	2.7
Antofagasta, Chile - Lat. 23°37'S Long. 70°16'W Elev. 519 m													
Dec. 1957	0	0	47	2.5	2.2	4.2	4.5	0.51	1.0	0.48	0.0110	4.2	2.0
Santiago, Chile - Lat. 33°27'S Long. 70°42'W Elev. 520 m													
Dec. 1957	-	N.R.	32	5.3	2.9	12	4.0	0.54	1.4	-	0.0170	5.4	2.6
Pearl Harbor, Hawaiian Islands - Lat. 21°22'N Long. 157°58'W Elev. 5 m													
April 1957	N.R.†	41	190	18	12	28	19	1.0	3.0	0.86	0.0053	12	3.0
May 1957	N.R.	1	130	9.5	11	19	9.6	0.46	1.8	0.95	0.0035	24	3.9
June 1957	N.R.	2	180	7.8	19	30	17	1.1	2.1	0.56	0.0061	17	1.9
July 1957	N.R.	9	270	140	55	77	20	0.90	1.8	-	0.0033	61	2.0
Aug. 1957	N.R.	4	100	16	12	19	8.5	0.48	0.98	-	0.0048	25	2.0
Oct. 1957	N.R.	1	160	47	21	30	12	0.41	1.3	0.47	0.0026	51	3.2
Nov. 1957	N.R.	48	100	14	9.2	8.7	7.3	0.44	0.57	0.05	0.0044	21	1.3
Dec. 1957	N.R.	30	180	59	17	34	17	1.0	1.2	-	0.0056	17	1.2
Mauna Loa, Hawaiian Islands - Lat. 19°28'N Long. 155°36'W Elev. 3394 m													
Oct. 1957	N.R.	43	140	33	18	25	11	0.92	1.2	0.81	0.0066	20	1.3
Nov. 1957	N.R.	46	300	43	29	59	24	1.3	2.5	0.37	0.0043	22	1.9
Dec. 1957	N.R.	62	330	64	32	58	26	1.4	2.5	-	0.0042	23	1.8
Subic Bay, Philippines - Lat. 14°49'N Long. 120°17'E Elev. 18 m													
July 1957	N.R.	N.R.	31	7.4	3.2	4.5	2.1	0.20	0.26	0.35	0.0065	16	1.3
Aug. 1957	N.R.	N.R.	32	6.7	3.5	5.6	2.5	0.10	0.22	-	0.0031	35	2.2
Sept. 1957	N.R.	N.R.	57	4.9	5.1	9.5	5.1	0.31	0.68	-	0.0054	16	2.2
Oct. 1957	N.R.	N.R.	43	13	6.7	8.4	3.9	0.16	0.38	-	0.0037	42	2.4
Nov. 1957	N.R.	N.R.	80	20	8.8	16	7.1	0.39	0.73	-	0.0049	23	1.9
Dec. 1957	N.R.	N.R.	38	1.9	4.1	7.4	3.5	0.20	0.37	-	0.0053	21	1.9

*Extrapolated to the middle of the collection period.

†Not reported.

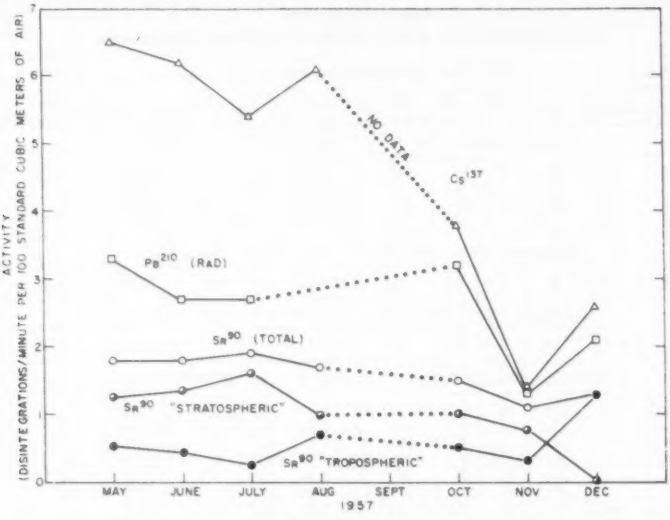

Fig. 2 - Long-lived fission products in the air at Washington, D. C., 1957

There are definite changes in concentration of the fission products Sr^{90} and Cs^{137} that occur during the period studied. There is presently insufficient data to say whether these changes are seasonal in nature or whether they are the result of recent atomic explosions. The low values of the long-lived materials in the air at Miraflores, Panama Canal Zone, are definitely related to the rainy season there.

Latitudinal Variation of Long-Lived Activity in the Air

In Fig. 4, the radioactivity of Cs^{137} and Sr^{90} in the air is plotted against the latitude of the collecting site along the 80th meridian for December 1957. There is a definite maximum in the concentrations of both these fission products in the midlatitudes of both hemispheres with a definite minimum near the Equator. These data are strikingly similar to that collected at an earlier date from the network of stations operated by the British (5). Integration of the concentrations of these materials in the air between 0° and 35°N and 0° and 35°S, indicates the air concentration of Sr^{90} and Cs^{137} in this part in the Northern Hemisphere to be approximately twice that in a similar area to the south. This difference is not nearly so great as that obtained from a similar comparison of the gross β emitters during this same period (7).

Contribution of Sr^{90} to Total Fission Product Activity

Evidence of the introduction of bomb debris of recent origin into the air masses sampled may be readily noted in Fig. 5, where the percentage of Sr^{90} in the gross fission products is plotted against the month of collection. The progressive decrease in the Sr^{90}/gross β ratio during May through early October at Washington, Miraflores, and Miami is due to

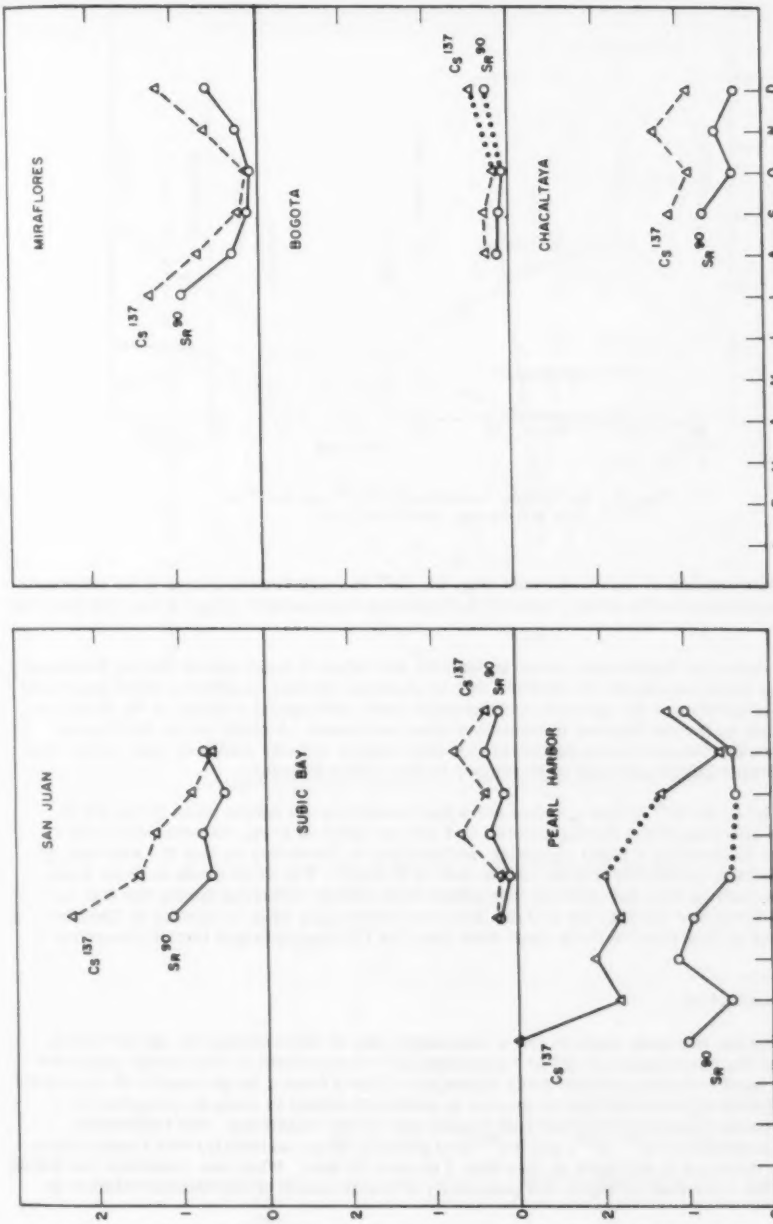

Fig. 3 - Long-lived fission products in the air

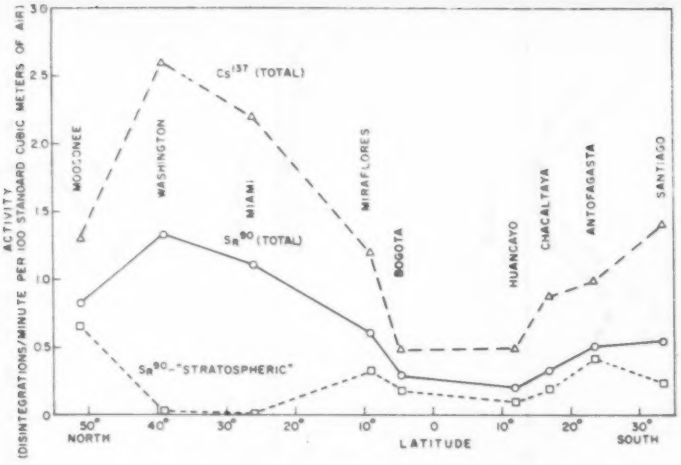

Fig. 4 - Latitudinal variation of Sr^{90} and Cs^{137} in the air during December 1957

the Plumbbob series of tests in Nevada (Fig. 6). Sr^{90} in fresh fission debris is an extremely minor contributor to the gross β activity but becomes increasingly important as the material ages.

The curve for Miraflores seems to indicate the influx of fresh debris during November; it appears most reasonable to attribute this to changing weather conditions which permitted a larger proportion of the general contamination from subtropical regions of the Northern Hemisphere to invade Panama in November than in October. A study of the daily gross activity measurements shows definitely that this fresher activity could not have come from the Christmas Island test held in November by the United Kingdon.

In Fig. 5, the Sr^{90}/gross β ratios show that relatively old debris were in the air at Huancayo and Chacaltaya during October and that an influx of fresh material occurred in November followed by a rapid cleansing or dispersal in December so that the average age of the debris in December was not unlike that of October. The daily gross activity measurements confirm this and indicate that rather high activity occurred during the last two weeks of November but that the activity level was essentially back to normal by December 1. The source of this fresh activity must have been the Christmas Island test of November 8.

Age Determination

An attempt has been made to find a meaningful way of determining the age of fission debris and the contribution of old or "stratospheric" componemts to the activity collected. This is a most complex problem since radioactive debris from a large number of explosions occurring over a period of days or months to years are mixed in unknown proportions. Further, these explosions involved both fission and fusion reactions. The fissionable material consisted of U^{235}, U^{238}, and Pu^{239} (and possibly other materials) with fission being caused by neutrons of energies of less than 1 to over 14 Mev. When one considers the fission yields of the individual isotopes, the possibility of fractionation of one isotope relative to

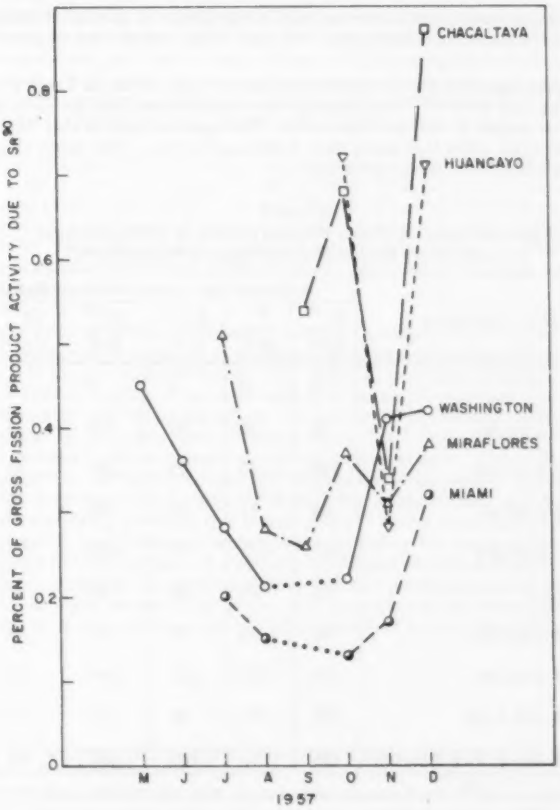

Fig. 5 - Variation in the Sr^{90} contribution to the gross fission product activity of the air

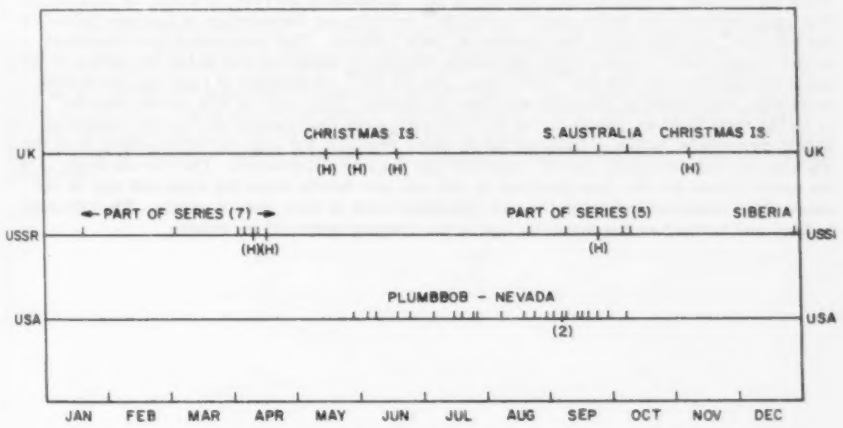

Fig. 6 - Nuclear detonations announced by the United States and United Kingdom, 1957 (courtesy of the U.S. Weather Bureau)

another, and the unknown ages of the various components, it is readily apparent that no simple division of fission products into "old" and "new" categories is possible.

The apparent ages of several synthetic mixtures are shown in Table 2, where the source material is assumed to be U^{235} fissioned by thermal neutrons and the ages are determined from ratios of isotopes of various half-lives. The apparent age is that which would give the indicated activity ratio that many days following fission. This table is included solely to point out the complexity of the problem.

Table 2
Apparent Ages of Mixed Fission Debris of Different Ages from Activity Ratios of Some High-Yield Isotopes*

Composition of Mixture	Apparent Age from Indicated Ratio (days)					
	$\frac{Sr^{89}}{Sr^{90}}$	$\frac{Y^{91}}{Sr^{90}}$	$\frac{Ce^{141}}{Sr^{90}}$	$\frac{Ce^{144}}{Sr^{90}}$	$\frac{Ce^{141}}{Ce^{144}}$	$\frac{Ce^{141}}{Y^{91}}$
100% new	0	0	0	0	0	0
60% new, 40% 1 yr old	35	40	20	105	12	1
20% new, 80% 1 yr old	120	130	65	260	43	1
60% new, 40% 2 yr old	39	41	20	160	9	1
20% new, 80% 2 yr old	121	132	67	425	22	1
all 40 days old	40	40	40	40	40	40
50% 40 d, 50% 1 yr old	90	95	70	170	55	41
50% 80 d, 50% 1 yr old	130	135	110	195	99	80
50% 60 d, 50% 180 d old	100	100	90	110	85	70
33% 60 d, 33% 180 d, 33% 1 yr old	126	130	105	180	95	80

*Based on fission of U^{235} by thermal neutrons, S. Katcoff, Nucleonics 16(No,4):78 (1958).

In view of this complexity, two simplified approaches were considered. In one, the assignment of activity into "old" and "new" categories was made by assuming all short-lived material (Ce^{141} or Y^{91}) to have been created at the midpoint of the collection period. Thus the number of fissions (or activity of Sr^{90} associated therewith) could be calculated. The ratio between the above and the total Sr^{90} activity, or the number of fissions based on the total Sr^{90} activity, gave the fraction of "new" debris. The remainder was therefore, by definition, "old." In the other approach, the newer material was dated by means of the apparent age given by the Ce^{141}/Y^{91} ratio, and the Sr^{90}, or number of fissions associated therewith, calculated at the apparent time of fission. The ratio of this to the total Sr^{90}, or to the total fissions based on the Sr^{90} activity, gave the fraction of "newer" material. In this procedure, which is believed to be more realistic but still far from exact, both the fraction of fresh material and its apparent age may be determined. The two methods give the same values for the contributions of old and new debris when the apparent age of the short-lived material indicates the new material to be of very recent origin. They diverge farther and farther as the apparent age of the fresher material increases.

If we redefine our terms, ignore some of the inherent difficulties, and instead of "newer" say "tropospheric" and for "old" say "stratospheric" to indicate arbitrarily the origins of these materials, we have a rough means of comparing the relative contributions of these two sources. This latter, more realistic approach has been used to determine the apparent age of the tropospheric debris and the assignment of the Sr^{90} activity to a tropospheric or stratospheric origin. These data are presented in Table 3.

It may be readily seen that generally a large fraction of the observed Sr^{90} activity appears to have a stratospheric origin. It should be pointed out that, if the first method discussed were employed, even more of the Sr^{90} would be assigned to a stratospheric source. The apparent age in days of the tropospheric debris was obtained from the activity ratio of Ce^{141}/Y^{91} using the relation displayed graphically in Fig. 7. The assignment of Sr^{90} (or original fissions contained in the sample) was obtained through use of the equations outlined in Appendix B.

In general the results appear reasonable—the tropospheric debris appears to age as expected following the end of a series of nuclear explosions. Further, the tropospheric component of Sr^{90} in the air at Washington, D.C. (Fig. 2), is highest during August, September, and October 1957 at the time the contribution from the Nevada tests was high. The lower value obtained in July when the gross air activity also was high may be due to the difficulty in obtaining an accurate determination of the Ce^{141} in the presence of large quantities of Ce^{144} remaining in the air from the spring series of tests in the USSR or from the stratospheric reservoir. In addition, the Cs^{137} values were extremely high during this period. Again, the high value for tropospheric Sr^{90} during December may be due to the same problem of accurately counting low levels of Ce^{141} in the presence of large quantities of Ce^{144}. The apparent age of about 4 months here indicates the large decay correction that must be applied to this isotope. A similar, seemingly unreasonable result is obtained at Miami for the same month. It seems unlikely that the stratospheric deposition would be so low relative to other times of the year. The variation in the stratospheric contribution to collections at various sites along the 80th meridian during December is shown in Fig. 4.

CONCLUSIONS

Because of the limited radiochemical data presented in this report, it is impossible to obtain a clear-cut indication of the seasonal or long-term changes in the air concentration of fission products. Moreover, the spasmodic introduction of fresh debris into the atmosphere makes for increased difficulty. However, several generalizations can be made:

1. The concentration of all fission products is considerably higher in the Northern Hemisphere than in the Southern Hemisphere. A minimum occurs near the Equator.

2. The relative contribution of Sr^{90} to the total activity is higher below the Equator, indicating a higher proportion of "old" or "stratospheric" debris there.

3. The concentration of Sr^{90} in the ground-level air is only a factor of 2 or 3 higher in the Northern Hemisphere for corresponding latitudes along the 80th meridian. Similar differences also occur for different longitudes near the Tropic of Cancer. It seems reasonable to accept the postulate that mixing across the Equator does occur in the stratosphere, but it is presently impossible to determine the rate or extent of such mixing. Without the confusion created by the introduction of fresh debris, both the extent of mixing and the rate of depletion of the stratospheric reservoir could be obtained from such measurements.

Table 3
Apparent Age of the Tropospheric Debris and the Magnitude of the Stratospheric Contribution to the Sr^{90} in the Air

Month 1957	Activity Ratio Ce^{141}/Y^{91}	Apparent Age of Tropospheric Debris (days)	Source of Sr^{90}	
			"Troposphere" (percent)	"Stratosphere" (percent)
Moosonee, Ontario				
Nov.	1.34	40	27	73
Dec.	1.47	33	20	80
Washington, D. C.				
May	1.25	50	30	70
June	1.79	18	25	75
July	2.26	<0	14	86
Aug.	1.25	45	42	58
Oct.	1.81	15	34	66
Nov.	1.19	45	30	69
Dec.	0.52	122	98	2
Miami, Florida				
July	1.03	65	63	37
Aug.	1.23	45	78	22
Oct.	2.14	5	43	57
Nov.	0.79	80	-	-
Dec.	0.76	85	100	0
San Juan, Puerto Rico				
July	1.14	45	68	32
Aug.	1.31	40	62	38
Sept.	2.60	<0	52	48
Oct.	1.43	35	43	57
Nov.	0.81	80	35	65
Miraflores, Panama Canal Zone				
July	0.75	90	46	54
Aug.	0.89	68	62	38
Sept.	1.30	45	64	36
Oct.	0.22	185	-	-
Nov.	3.10	<0	13	87
Dec.	0.96	65	47	53
Bogota, Colombia				
Aug.	0.83	78	85	15
Sept.	0.66	95	86	14
Oct.	0.12	235	-	-
Dec.	1.08	57	38	62
Quito, Ecuador				
Sept.	1.37	40	-	-
Oct.	0.58	110	32	68
Nov.	0.47	125	-	-

Table 3 (Continued)
Apparent Age of the Tropospheric Debris and the Magnitude of the Stratospheric Contribution to the Sr^{90} in the Air

Month 1957	Activity Ratio Ce^{141}/Y^{91}	Apparent Age of Tropospheric Debris (days)	Source of Sr^{90}	
			"Troposphere" (percent)	"Stratosphere" (percent)
Lima, Peru				
Dec.	0.62	105	60	40
Huancayo, Peru				
Oct.	no Ce^{141} detected		0	100
Nov.	1.90	15	39	61
Dec.	0.52	115	50	50
Chacaltaya, Bolivia				
Sept.	1.11	55	62	38
Oct.	0.64	100	42	58
Nov.	1.16	52	52	48
Dec.	0.34	150	44	56
Antofagasta, Chile				
Dec.	0.60	105	17	83
Santiago, Chile				
Dec.	0.45	125	58	42
Pearl Harbor, Hawaiian Islands				
Aug.	0.83	78	61	39
Oct.	1.57	28	61	39
Nov.	1.59	28	17	83
Dec.	1.73	20	25	75
Mauna Loa, Hawaiian Islands				
Oct.	1.33	40	25	75
Nov.	0.72	85	69	31
Dec.	1.10	55	47	52
Subic Bay, Philippines				
July	1.63	23	17	83
Aug.	1.21	45	39	61
Sept.	0.51	120	82	18
Oct.	1.59	55	85	15
Nov.	1.25	45	41	59

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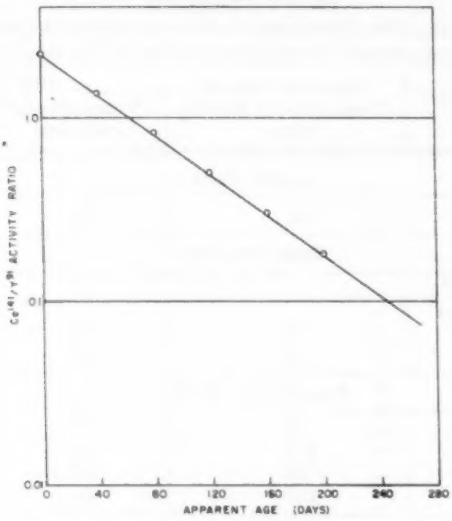

Fig. 7 - Apparent age of fission product mixture from Ce^{141}/Y^{91} activity ratio

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APPENDIX A

Determination of Counting Rate of Y^{90} in Samples of Low Activity

In order to avoid the difficulties inherent in determining graphically the initial activity of samples containing relatively few counts per minute of Y^{90}, an exact equation has been employed which depends on the sum of consecutive counts during an extended counting period. This summation technique averages out the variations in the individual hourly counting rates and, further, gives results which are statistically more reliable. In our present counters, it is estimated that the standard deviation of our actual counting rates of Y^{90} (background subtracted) is less than ±0.05 c/m at a counting rate of 1.0 c/m.

For a number of consecutive hourly counts (t), the expression employed is

$$(c/m)_o = \frac{\lambda}{1 - e^{-\lambda t}} \sum_o^t (c/m)_t$$

where $(c/m)_o$ = calculated counting rate for the first hour of counting

$(c/m)_t$ = measured average hourly counting rate for each hour

$\lambda = 0.693/t_{1/2} = 1.075 \times 10^{-2}$ hr^{-1} for Y^{90}.

This expression reduces to the following for a 72-hour period of consecutive hourly counts, where $\sum_o^{72} (c/m)_t$ is the sum of these average hourly counting rates:

$$(c/m)_o = 1.994 \times 10^{-2} \times \sum_o^{72} (c/m)_t.$$

The counting rate thus obtained for the first hour of counting, $(c/m)_o$, is corrected for decay to the time of separation of the Y^{90} from the parent Sr^{90}.

APPENDIX B

Determination of the Contribution of Stratospheric Debris to the Sr^{90} In the Air at Ground Level

If we assume that the Ce^{141}/Y^{91} activity ratio defines the age of the short-lived material in the air and that the activity of these relatively short-lived isotopes is due solely to debris formed at that time, we may calculate the number of fissions associated with this activity. Thus

$$A_o^{141} = A_t^{141} e^{\lambda t}$$

where A_o^{141} = atoms of Ce^{141} from assumed nuclear test

A_t^{141} = measured atoms of Ce^{141}

λ = decay constant for 28-day Ce^{141}

t = assumed elapsed time from nuclear explosion.

Since

$$N_1 = \frac{A_o^{141}}{Y^{141}\lambda}$$

then

$$N_1 = \frac{A_t^{141} e^{\lambda t}}{0.060\lambda}$$

where N_1 = fissions in sample from assumed test

$Y^{141} = 0.060$ = fission yield of Ce^{141} (U^{235}, thermal neutrons).*

Total fissions in the air sample are similarly given by the expression

$$N_2 = \frac{A_o^{90}}{0.0577\lambda_2}$$

where $A_o^{90} = A^{90}$ = atoms Sr^{90} in the total air sample (assuming negligible decay of Sr^{90} since latest shot date)

0.0577 = fission yield of Sr^{90} (U^{235}, thermal neutrons)*

λ_2 = decay constant for 28-year Sr^{90}.

*S. Katcoff, "Fission-Product Yields from U, Th, and Pu," Nucleonics 16(No. 4):78 (1958)

The fraction of fissions or of Sr^{90} due to material of recent origin, by our definition the "tropospheric" component, is given by the ratio N_1/N_2, and the material of older origin, the "stratospheric" component, is given by $(N_2 - N_1)/N_2$.

Obviously, any combination of short-lived and long-lived isotopes could be used to define an age for the tropospheric debris and to determine the tropospheric and stratospheric contributions to the Sr^{90} activity. It is felt that the ratio of activities of two isotopes of relatively short half-life and which are relatively insensitive to the type of nuclear explosion will give the truest picture of the stratospheric contaminant.

STRATOSPHERIC RADIOACTIVITY DATA OBTAINED BY BALLOON SAMPLING

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Statement submitted for Public Hearings on Fallout from Nuclear Weapons Tests, held by the Joint Committee on Atomic Energy, Special Subcommittee on Radiation, May 5-8, 1959.
(Revised June 18, 1959)

Introduction

One of the hypotheses formulated during the Rand "Sunshine" study in the summer of 1953 (The Rand Corporation Report R-251-AEC, 1953) was that a significant part of the radioactive debris, both gaseous and fine particulate, from a high-yield nuclear detonation would be injected into the stratosphere and would remain suspended there for a period of the order of years before settling back to earth.

In the following paragraphs I shall outline briefly the various methods which have been used to collect samples in the stratosphere by unmanned balloon ascents. This is a compilation of the results of work by others. Some results of analysis and interpretation are quoted in the text and others are appended. It has not been practicable to acknowledge many of the important individual and agency contributions to these projects.

Electrostatic Precipitator, 1953-54

Following the Rand study, the New York Operations Office of the AEC undertook to quickly develop an electrostatic precipitator to collect stratospheric particulate debris for strontium-90 analysis. From December 1953 to July, 1954 with the cooperation of the Air Force samplers of this type were flown successfully 23 times at Holloman AFB, N.M., at altitudes of 80,000 to 100,000 ft. A pair of sampling units ready for launching is shown in Figure 1.

Unfortunately the collection efficiency of the precipitator was not known in advance for the voltages used, which were set safely below the breakdown voltage for such low ambient pressures (about 1/100 atmosphere). In later laboratory tests, the efficiency turned out to be about 17% under simulated flight conditions. Combined with the relatively low air flow rate through the precipitator, this did not provide large enough samples for radiochemical analysis.

Relative concentrations of total beta activity were recorded, however, and are shown in Table 1 and Figure 2. The large rise of stratospheric radioactivity over New Mexico in mid-April about six weeks after the Bravo event of the Castle series, is clearly evident in this chart. The flights were discontinued in July 1954 and an investigation of the collection characteristics of the device was undertaken. This resulted in the report NYO-4708, "Experimental Collection Efficiency of a Stratospheric Air Sampler", by Loysen, Breslin and Di Giovanni.

Carbon-14, 1953 to present

A program of analyzing stratospheric whole air samples for carbon-14 was begun in 1953 at General Mills, Inc., Minneapolis, Minn. Later with the cooperation of the U.S. Air Force balloon launchings were also made from San Angelo, Texas, Panama Canal Zone, and Sao Paulo, Brazil. The technique is described in Appendix A. The Carbon-14 analyses have been performed by Dr. F. T. Hagemann of Argonne National Laboratory. The resulting data provide information related to the total yield of test devices, including both fission and fusion. They have recently been declassified and are listed in Appendix A. These figures are not final, since work is still in progress to determine certain experimental errors and correction factors. While not providing direct information on the particulate fission products such as Sr^{90} and Cs^{137}, these carbon-14 data do permit some general studies of transport and mixing rates for stratospheric bomb debris.

Tritium, 1955-1958

Measurements of tritium (hydrogen-3) in some of the stratospheric whole air samples collected over Minneapolis were made by using a special heavy water tracer technique. The data, with a description of the method, are also

contained in Appendix A.

"Ash Can" particulate filter system - 1956 trial operations

In a second attempt to obtain quantitative particulate fission product data, a high altitude balloon borne filter system was developed by General Mills, Inc. Because of its shape and size, shown in Figure 3, it was nicknamed "Ash Can".

Between February 9 and April 10, 1956, five test flights were made at Minneapolis at altitudes from 48,500 to 68,000 ft. Twelve further trials, of which 9 were successful, were conducted in cooperation with the Air Force at San Angelo, Texas from April 12 to May 5, 1956. Altitudes ranged up to 92,000 ft.

The samples from these two series of preliminary flights were analyzed by the AEC Health and Safety Laboratory and the results are shown in Table 2.

In order to determine the filtering efficiency of the Ash Can system, four inter-comparisons were made with Air Force sampling aircraft at 40,000 ft. over Minneapolis in the summer of 1956 (Appendix B). A further intercomparison was made at 50,000 ft. in the Spring of 1958. The resulting data are given in Table 3. The velocity with which the air flows through the aircraft filter is such that the collection efficiency approaches 100% even for particles as small as 1/10 micron in diameter. From these calibration flights a preliminary figure of 20 to 25% was obtained for the Ash Can collection efficiency. However, it was recognized that this figure might not be applicable at higher altitudes.

Project Ash Can Particulate Sampling - Regular Operations

Starting in November 1956, regular Ash Can particulate sampling operations were begun as a part of the cooperative program with the U.S. Air Force at its

bases at San Angelo, Canal Zone and Sao Paulo, and through contract with General Mills, Inc. at Minneapolis. Analysis of samples has been by commercial radiochemical laboratories under the supervision of the AEC Health and Safety Laboratory. All results available to date are given in Appendix C.

In July, 1958, the operations were shifted from the contractor at Minneapolis to an Air Force detachment at Sioux City, Iowa. In January and March, 1959, Air Force balloon activities detachments were withdrawn from the Canal Zone and Sao Paulo stations, respectively, terminating Ash Can operations at those sites. Sampling operations are continuing at San Angelo and Sioux City.

Ash Can Collection Efficiency

The total mass of stratospheric dust collected in an Ash Can sample is probably of the order of a microgram or less deposited on 5 square feet of filter paper. The mass of strontium-90 collected is seldom more than a micromicrogram (1/1,000,000,000,000 gm or 1/30,000,000,000,000 oz.). The largest number of particles generated by condensation in a nuclear fireball, as well as most of the natural dust particles present in the stratosphere, are probably less than 1/10 micron in diameter (that is, less than 4 millionths of an inch).

The fibers of the filter paper, on the other hand are, on the average, 17 microns in diameter and 170 microns apart. This large, coarse, highly porous paper permits rapid filtration of large volumes of air with low resistance to flow and therefore low fan power. All these are advantageous characteristics giving large sample size, short balloon flight duration, and light load. The disadvantage is that a large proportion of the fine particles are carried through the pores and around the fibers without being intercepted.

Laboratory studies by Sidney Stern of General Mills, Inc., reported in a

separate statement submitted to these Hearings, have given a fairly complete picture of the filtration efficiency of the paper over a wide range of altitudes (simulated by low pressure in the laboratory apparatus), particle sizes and air speeds. For the Ash Can air speed of 100 ft./min., Fig. 4 shows curves of filtration efficiency plotted against altitude for each of the particle sizes tested in the laboratory. The overall Ash Can collection efficiencies determined from five airplane comparisons and six recent balloon calibration experiments are also shown on this graph.

With one exception the experimental points from flight tests fall in the range of efficiencies corresponding to the laboratory results for 2/100 to 2/10 micron particles. The one exception appears to have been a case of stagnation of the balloon relative to the air, leading to recirculation of filtered air through the sampler several times. An exhaust duct has now been developed to prevent such recirculation.

An attempt has been made by Chicago Midway Laboratories under AEC contract to develop an absolute collector (Fig. 5) for in-flight calibration of the Ash Can system. This collector liquefies the stratospheric air. It has been operated successfully in several flights during 1958. However, due to difficulties of operation and sample recovery, this project is being terminated.

To summarize, the collection efficiency of the Ash Can system appears to be generally in the range 20 to 30% at 50,000 ft, 30 to 60% at 65,000 ft, 40 to 80% at 80,000 ft, and 50 to 90% at 90,000 ft. Occasionally recycling of filtered air or some other undetected malfunction may result in a grossly low collection. While the frequency of such occurrences does not appear likely to be larger than 10 or 20% based on internal consistency of the data, the effect would be to bias the data towards low values.

Evaluation of Ash Can Results

A recent study prepared by Dr. L. Machta and R. J. List of the U. S. Weather Bureau entitled, "Analysis of Stratospheric Strontium-90 Measurements" is attached as Appendix D. This paper evaluates the application of the Ash Can data to the problems of estimating the stratospheric Sr-90 inventory and testing hypothetical storage and transport models. The estimates of stratospheric Sr-90 inventory which they obtain, approximately 1 megacurie or less, are in substantial agreement with recent aircraft data from the Armed Forces Special Weapons Project.

Further Developments

Under AEC contract, General Mills, Inc., has developed a superior high-velocity filter system of much higher collection efficiency than the standard Ash Can but still preserving the volume flow and weight advantages. A 50-foot exhaust duct prevents recycling. This new unit is now being field tested prior to being placed in routine operation. GMI is also developing a new type of rotating impactor to obtain much more compact samples, and a stratospheric particle size classifier based on the cascade impactor principle.

Through another AEC contract with Del Electronics Corp., the electrostatic concept is being further developed. It promises to be capable of high collection efficiencies for very small particles and with virtually no resistance to air flow. Thus power and weight requirements would be reduced.

In other AEC contracts, basic studies of other concepts with possible application to high-altitude particulate sampling are being conducted. These include thermal precipitation, supersonic impaction (for rocket application) and centrifugal separation.

The Air Force Cambridge Research Center is also engaged in studies of natural and bomb-produced particulates in the stratosphere under the direction of Dr. E. A. Martell, with partial AEC support. Balloon-borne impactors and condensation nuclei counters are used for the dust studies. Sensitive radiochemical techniques have been developed to study the Hardtack high altitude rhodium-102 tracer at very low concentations,

TABLE 1

Radioactivity of Stratospheric Particulate Samples Collected by Electrostatic Precipitator, Holloman AFB, N. M.

Date	Altitude (ft)	Number of Samplers	Total activity (dpm/m^3)		Remarks
12-8-53	88,000	2	.06	.01	
12-15-53	95,000	1	.01		
1-5-54	93,000	2	.007	.014	
2-3-54	87,000	2	.004	.007	
2-10-54	101,000	2	.033	.024	Recovered 3-9-54
3-3-54	89,000	1	.012		
3-26-54	80,000	2	.01	.002	
4-1-54	88,000	2	.046	.043	
4-6-54	88,000	2	.015	.016	
4-15-54	85,000	2	.907	1.074	
4-22-54	80,000	2	.563	.019	One unit failed (batt. short)
4-27-54	90,000	2	.153	.133	
5-3-54	90,000	2	.078	.020	
5-12-54	85,000	2	.267	.025	Failure suspected
5-25-54	87,000	2	.046	.090	
5-28-54	82,000	2	.086	.103	
6-2-54	85,000	2	.006	.044	
6-8-54	82,000	2	-	.091	One damaged on impact.
6-14-54	60-80,000	2	.358	.401	
6-22-54	80,000	2	.069	.070	
6-29-54	85,000	2	.057	.106	
7-7-54	85,000	2	.09		Mean (details missing)
7-23-54	-	-	.075		Mean (details missing)

TABLE 2. Early Ash Can Trial Samples

Date	Altitude (ft)	Volume (scf)	Total Activity c-date	Total Activity dpm/scf	dpm/1000 scf Sr^{90}	dpm/1000 scf Sr^{89}(a)	dpm/1000 scf Cs^{137}
a. Minneapolis, Minn.							
2-9-56	67,000	470			92		
3-9-56	48,500	1253			63		
3-19-56	68,000	1270			82		
4-10-56	65,000	1015			41		
4-15-56	65,900	1085			36		
b. San Angelo, Texas							
4-12-56	60,000	3050	4-23-56	1.14±.01	46±2	188±5	67±3
4-13-56	77,500	2000	4-23-56	0.23±.01	13±3	14±5	24±4
4-16-56	59,700	3800	5-16-56	0.97±.01	36±2	88±6	-
4-29-56	88,750	1210	5-16-56	0.38±.01	31±5	≤8	-
5-2-56	59,000	4570	5-17-56	1.15±.01	39±2	59±4	90±3
5-3-56	76,000	833	5-18-56	0.35±.02	19±6	36±12	64±8
5-3-56	90,500	1310	5-17-56	0.17±.02	10±4	28±10	40±7
5-4-56	76,500	1842	5-18-56	0.18±.01	18±7	≤18	35±5
5-4-56	91,600	-	5-18-56	225±11(b)	22±6(b)	15±13(b)	88±10(b)
5-5-56	92,000	1220	5-18-56	0.32±.01	18±5	≤10	75±9

(a) Corrected to sampling date.
(b) Per whole sample

TABLE 3. Data obtained on samples collected March 6, 1958 over Minneapolis by AFSWP HASP aircraft and General Mills Ash Can balloon.

		Alt.	Time	10^3SCF	Activity in dpm/1000 SCF			
					Total Beta	Sr^{90}	Sr^{89}	Zr^{95}
Balloon:		48.7K	1505-1608Z	5.49	2300	24.4	154	241
Aircraft:	(1)	50K	1438-1508Z	9.40	9220	126	346	1214
	(2)	48K	1510-1542	10.63	10,240	111	730	1132
	(3)	49K	1544-1616	10.43	10,200	121	277	725
	(4)	49K	1618-1648	9.78	8790	108	673	1386
Weighted average:		48.5K	1505-1608Z		10,180	116	526	971
"Efficiency": 100% x Balloon/Aircraft:					22.4%	21.0%	29.3%	24.8%

Note: K = 1000 ft.

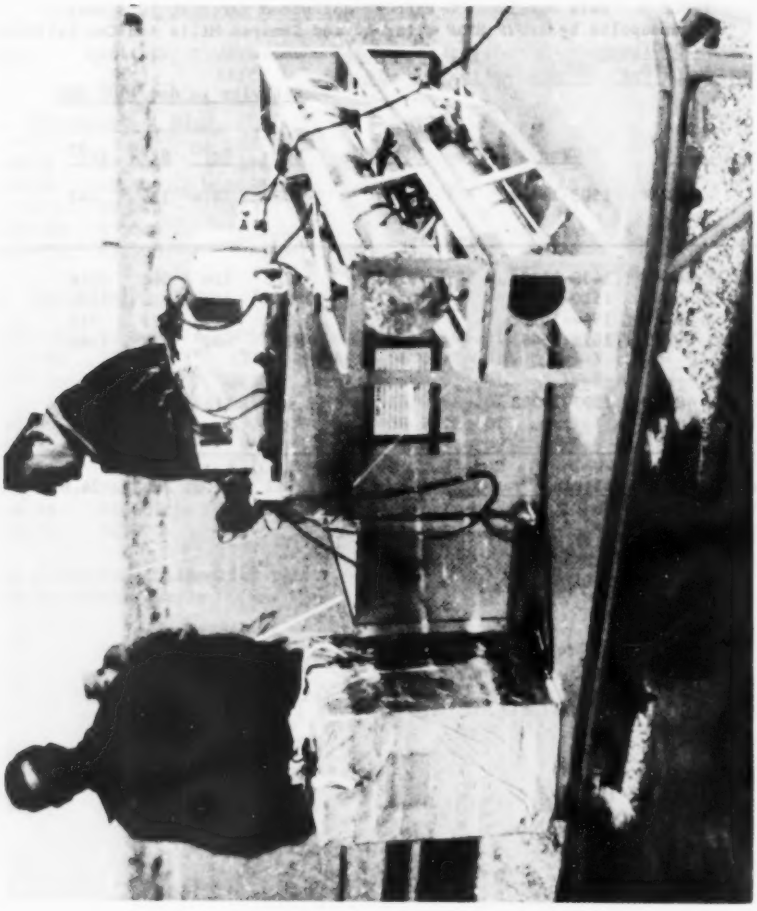

Fig. 1 —Two electrostatic precipitators with control, communication and power packages, ready for stratospheric balloon launching, Holloman Air Force Base, Dec. 8, 1953.

munication and power packages, ready for stratospheric balloon launching, Holloman Air Force Base, Dec. 8, 1953.

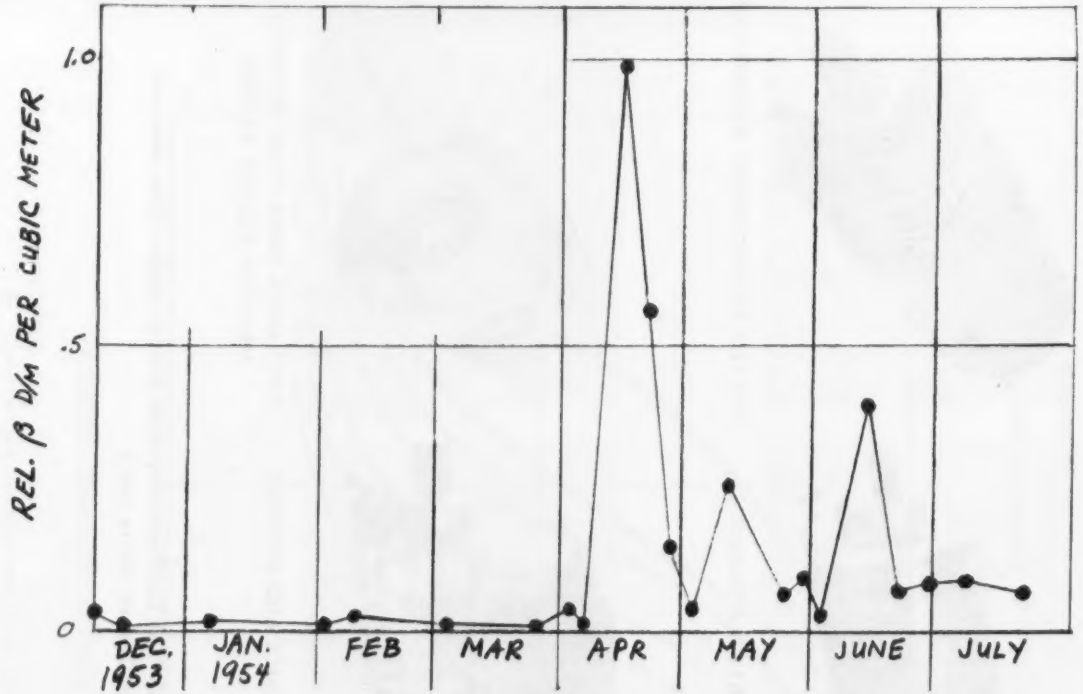

Fig. 2—Total β radioactivity (relative units) per cubic meter, 80,000 to 100,000 ft altitude, Dec. 8, 1953 to July 22, 1954, Holloman Air Force Base, N. M., from electrostatic precipitator samples (courtesy H. Di Giovanni).

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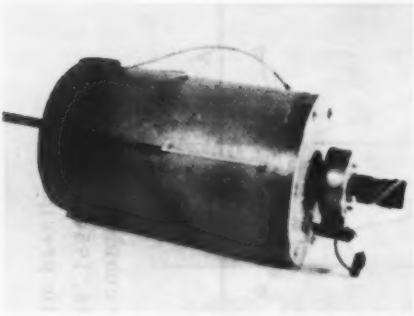
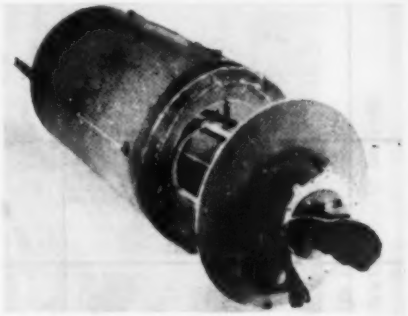
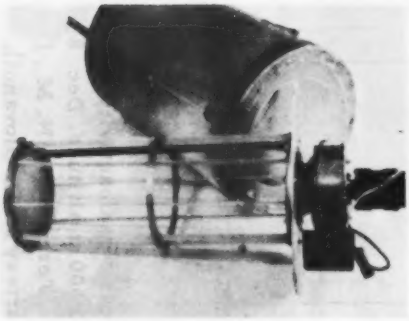


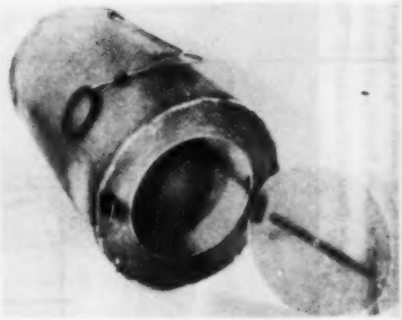
ASSEMBLED ASH-CAN



FILTER FRAME BEING WITHDRAWN



FILTER FRAME AND HOUSING



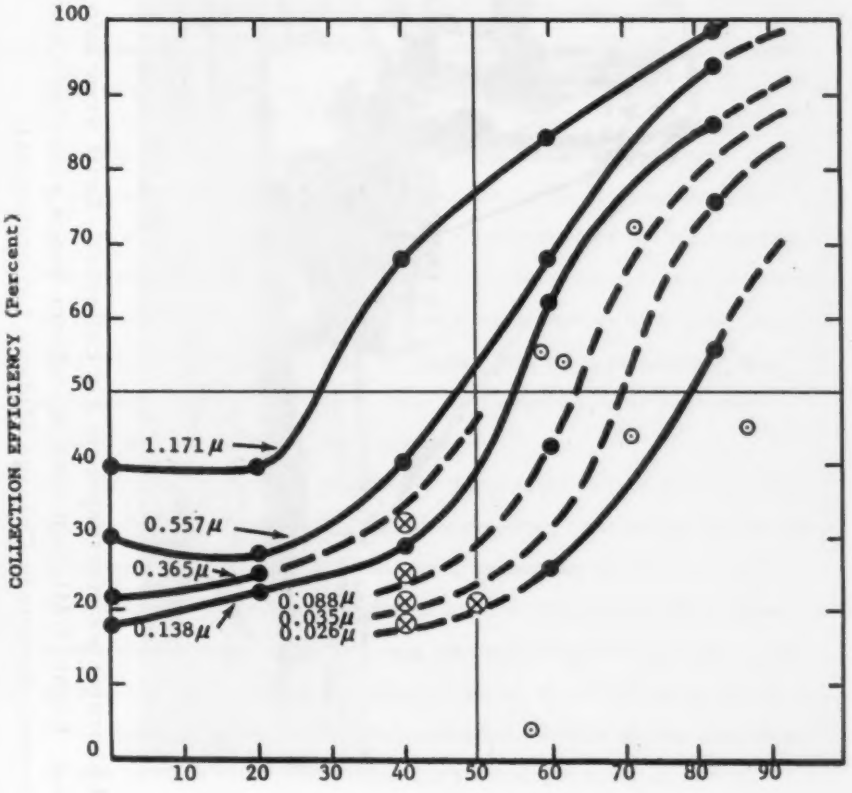
ENTRANCE DOOR OPEN SHOWING HEAD OF FILTER FRAME

Fig. 3—"Ash Can" stratospheric balloon-borne filter sampler (courtesy General Mills, Inc.).

COLLECTION EFFICIENCY (Percent)

FIGURE 4

ASH CAN COLLECTION EFFICIENCY



SYMBOLS:

● Laboratory measurements on IPC filter paper. Curve for each particle size labelled in microns. Dashed curves are extrapolated.

⊗ Ash Can comparison with aircraft samples (Sr-90 analysis).

⊙ Ash Can comparison with balloon-borne "Direct Flow" sampler at altitude.

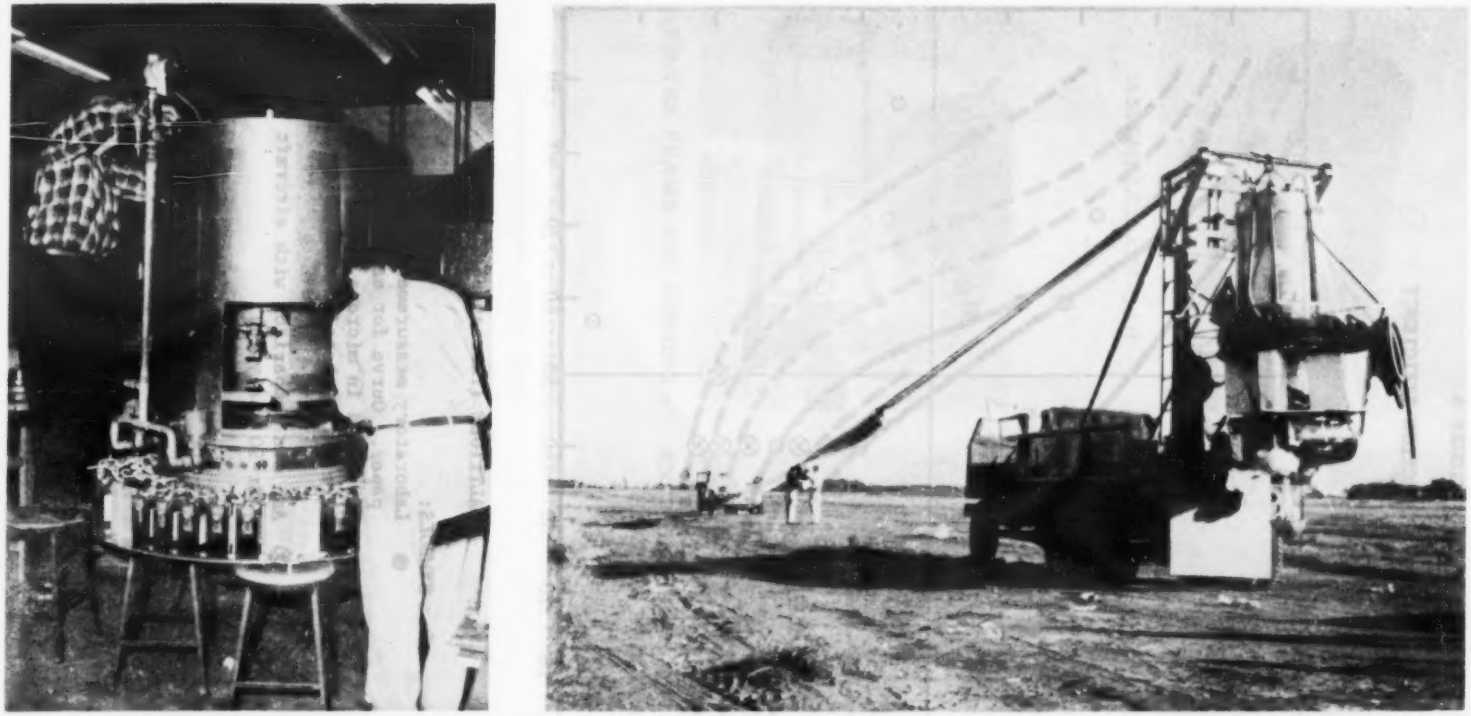


Fig. 5—Chicago Midway Laboratories stratospheric air collector. Left: view into receiver tank mounting space. Right: CML unit with styrofoam shock absorbers and two Ash Can units on launch truck (courtesy Chicago Midway Laboratories).

Stratospheric Carbon-14, Carbon Dioxide, and Tritium

French Hagemann*, James Gray, Jr.*, Lester Machta**, and Anthony Turkevich***

(based on an article by the same authors in Science, Vol. 130, No. 3375, pp. 542-552, 4 September 1959)

This article reports the results of measurements made in recent years of the carbon-14, carbon dioxide, and tritium in the stratosphere. The purpose of the measurements was to obtain information on the stratospheric concentrations of carbon-14 and tritium produced by the explosion of nuclear devices and to study the changes in these concentrations with time. Such data can be expected to furnish new insight into the circulation of the stratosphere, as well as to contribute to the evaluation of the hazards from nuclear explosions in the atmosphere.

The sampling program for carbon-14 was started in late 1953 at Minneapolis, Minn., and extended in 1955 to three other locations in the Western Hemisphere: San Angelo, Tex.; Canal Zone, Panama; and Sao Paulo, Brazil. The Minneapolis collection was shifted in June 1958 to Sioux City, Iowa. Carbon-14 was determined by measuring the specific activity of the carbon dioxide from air collected at altitudes between 45,000 and about 100,000 feet. Air samples were collected on a monthly schedule at four altitudes at each location unless operational difficulties prevented collection. The tritium measurements were performed only on samples collected at Minneapolis, primarily in the period 1957-58.

* Argonne National Laboratory

** U. S. Weather Bureau

*** Fermi Institute, University of Chicago

two Ash Can units on launch truck (courtesy Chicago Midway Laboratories).

This paper presents all of the significant original data as well as remarks on the experimental errors which lead to correction of some of the values and rejection of others. Many of the technical details are omitted from this paper. These, together with a further evaluation of the experimental uncertainties, data from later sampling, and a more extensive interpretation, will be published subsequently.

STRATOSPHERIC SAMPLING SYSTEM

Basic Equipment

A balloon-borne high altitude system was developed by General Mills, Inc.[1] to collect whole air samples from which the carbon-14 and tritium measurements were obtained. The collection system (Figures 1 and 2) consisted of four major components (1) lift balloon, (2) collection bag, (3) armored vessel, (4) control unit.

The lift balloon was a non-extensible plastic film (2 mil polyethylene) balloon of the "Skyhook" type. When the lift balloon reached its full size any excess helium was vented off through a duct system so that the balloon floated at a predetermined altitude during the collection period. After collection of the sample, an electrically operated trapdoor-type valve, built into the duct portion, released the exact amount of lift gas necessary to insure a controlled, safe descent of the system. A parachute was suspended directly beneath the balloon to help smooth the rate of descent and to prevent free fall of the equipment in case of balloon failure.

The collection bag was a large balloon fabricated of the same material as the lift balloon. Two sizes of collection bags were used, depending on

the collection altitude. A 47.5 foot diameter bag was used for collections at nominal altitudes above 80,000 feet while a 34.6 foot diameter bag was used for the collections at lower altitudes. A collection blower of the centrifugal type, powered by a 24 volt DC electric motor, was located below the collection bag.

When measurements were to be made of tritium, a dispenser was added to the system which introduced a measured amount of deuterium tracer, in the form of heavy water, into the contents of the collection bag at the time of sampling. The tracer was kept at a constant temperature of 95°C. About 2-5 grams of water vapor were dispensed uniformly with time at a point between the blower and bag during collection of the air sample. Both the collection bag and dispenser were effectively sealed at all other times. The amount of tracer introduced was determined by weighing the dispenser before and after each collection.

The final airborne sample container was a 1,400 cubic foot armored vessel to which the air sample was transferred from the collection bag before impact. It was constructed in 3 layers to preclude loss of the sample upon impact with the ground. The inner liner, gastight 4 mil polyethylene, was covered with a nylon fabric for protection against the heavy, coarse canvas "armor" of the outer bag. An axial flow blower was used to transfer the air from the collection bag to the armored vessel.

The control unit consisted of the power supply, the master control unit and the barograph, all housed in a large insulated red bag. An upward viewing sequence camera suspended below the control unit provided a positive record of the expansion of the lift balloon and the deployment of the collection bag.

Collection Procedure

The following sequence of events took place in a typical sample collection operation. The system was launched, rose to its floating altitude and began to float. The intake trapdoor valved on the collection blower open and the blower was turned on for the predetermined time required to fill the collection bag. After the collection blower was turned off, a trapdoor valve closed, sealing the sample air in the collection bag. The collection time varied from about one-half to one and one-half hours. The collection bag filled to about 2,000 standard cubic feet of air of which about 500 standard cubic feet were transferred to the armored bag. A spring-loaded valve on the balloon then opened allowing helium to escape and the system began its descent.

At approximately 33,000 feet, the transfer fan was energized and the transfer of the collected air from the collection bag to the armored vessel began. A barometric control automatically cut off the transfer fan when the 3,000 foot level was reached.

During these operations a recovery crew tracked the course of the flight visually, if possible, and with the aid of signals generated by a small radio transmitter included in the balloon train. The recovery crew, equipped with a four-stage compressor, arrived by truck as soon as possible at the impact area and transferred the air sample from the armored vessel to high pressure cylinders for shipment to the laboratory for subsequent processing and measurement.

Carbon dioxide was removed from some of the samples in a trap refrigerated with liquid nitrogen before passage of the air through the compressor into the high pressure cylinders. When a tritium analysis

was to be made, a portion of water vapor was frozen out of the sample air stream prior to entering the compressor.

STRATOSPHERIC ABUNDANCE OF CARBON DIOXIDE

Advantage was taken of the availability of stratospheric air collected in this program to measure the atmospheric abundance of carbon dioxide at high altitudes. A series of special small samples for this purpose were taken directly from the armored vessel to avoid possible alteration of the composition of the air in passage through the compressor and storage in the high pressure cylinders. These samples were collected in small (1.7 liter) stainless steel tanks, previously evacuated to a pressure of less than 10^{-3} mm Hg in the laboratory. Separate aliquots of the air samples were taken near the start and end of the transfer from the armored vessel to the high pressure cylinders. Such samples were obtained at each of the four collection stations during the summer and fall of 1956.

The carbon dioxide content was determined by pumping a measured amount (500 to 1000 cc) of air, previously dried by passage through anhydrone, through a capillary trap cooled with liquid nitrogen. The separated carbon dioxide was distilled from a -80°C bath into a second trap, cooled with liquid nitrogen, which was part of a capillary system of calibrated volume. The carbon dioxide was allowed to warm and expand and the pressure measured with a constant volume capillary manometer. Replicates, at least two in number, were run on each sample. The standard error of a single determination was estimated to be 0.5%, based upon observed recoveries from carbon dioxide-free air to which measured volumes of carbon dioxide had been added.

A similar series of direct air samples had been collected earlier

at Minneapolis during the winter of 1954. In this case single aliquots were taken in glass flasks fitted with stopcocks. The method of determination of carbon dioxide was similar to that described above, but with an estimated standard error of 1.0%.

The results of the measurements of the stratospheric abundance of carbon dioxide are shown in Table 1.

The table indicates no significant difference in the values obtained at Minneapolis in 1954 and in 1956. The agreement between the duplicate samples collected in 1956, with a few exceptions, is good. The samples collected at the start of transfer operations at Minneapolis on 1 August 1956 and at the Canal Zone on 1 August 1956 and 4 October 1956 gave values differing widely from those of the samples collected at the end of the transfer. These values can be ignored as being non-representative, probably due to poor sampling techniques. The average value at Minneapolis for altitudes studied is 312 ppm; at San Angelo, 310 ppm; at the Canal Zone, 312 ppm; and at Sao Paulo, 310 ppm. The average at about 50,000 feet for all locations is 311 ppm; at about 65,000 feet, 310 ppm; at about 80,000 feet, 313 ppm; and at about 90,000 feet, 310 ppm. The average abundance of carbon dioxide at all locations at altitudes of about 50,000 feet or greater is 311 ppm with an average deviation of less than 1% and a range of $\pm$ 2%. This value is in close agreement with recent determinations of the abundance and variability of carbon dioxide in the troposphere[2].

STRATOSPHERIC CONCENTRATION OF CARBON-14

Sample Processing and Measurement of Radiocarbon[3]

The initial separation of carbon dioxide from the compressed air samples was accomplished in the laboratory by standard freeze-out techniques. Where freeze-out traps were used in the field, the separated carbon dioxide

TABLE 1

STRATOSPHERIC ABUNDANCE OF CARBON DIOXIDE

Location	Collection Date	Altitude, 10^3 ft	Carbon Dioxide Abundance, ppm
Minneapolis, Minnesota	19 Oct 1954	50	318
	4 Nov 1954	50	316
	4 Dec 1954	51	311
	27 Dec 1954	61	308
	10 Jan 1955	60	309
	23 Jan 1955	60	308
	15 Oct 1954	64	315
	27 Oct 1954	66	312
	2 Nov 1954	66	309
	19 Dec 1954	65	310
	29 Dec 1954	66	308
	27 Dec 1954	71	308
	6 Jan 1955	73	310
	20 Oct 1954	79	317
	30 Nov 1954	79	316
	6 Dec 1954	79	311
			Start / End
	2 Oct 1956	52	308 / 309
	12 Sep 1956	65	307 / 310
	1 Aug 1956	71—61	337 / 309
	16 May 1956	83	309 / 310
	13 Aug 1956	80	311 / 323
	30 Aug 1956	90	319 / 315
San Angelo, Texas	6 Aug 1956	47	308 / 312
	7 Aug 1956	65	307 / 309
	16 Oct 1956	79	312 / 310
	25 Aug 1956	94	309 / 309
Canal Zone, Panama	7 Aug 1956	54	319 / 314
	1 Aug 1956	67	258 / 314
	21 Oct 1956	87—83	312 / 318
	4 Oct 1956	97	346 / 304
Sao Paulo, Brazil	18 Aug 1956	50	309 / 309
	29 Aug 1956	68—65	309 / 307
	17 Aug 1956	82—80	315 / 309
	16 Aug 1956	92—90	311 / 311

was shipped to the laboratory in the stainless steel trap itself which was closed with high pressure valves.

The separated carbon dioxide was purified for counting by the following procedure:

1. Freezing and pumping at -196°C
2. Reacting with CaO at 700 to 750°C to form $CaCO_3$
3. Pumping the $CaCO_3$ to a high vacuum at 450°C
4. Liberating the CO_2 by heating the $CaCO_3$ to 900°C
5. Freezing and pumping again at -196°C

The radiocarbon was measured in proportional counters utilizing the purified carbon dioxide as the counter fill. Considering the large number of samples to be measured, a sample size in the range of one to two liters of carbon dioxide was chosen as the best compromise between the convenience of sample preparation and accuracy of the measurement.

The counters, 3 inches in diameter and 25 inches long, were constructed of stainless steel with a 1 mil stainless steel anode center wire and had a sensitive volume of about 2.2 liters. The counter tubes, surrounded by a ring of anticoincidence geiger counters and 12 inches of steel shielding, exhibited backgrounds of about 17 counts per minute when filled with one atmosphere of inert carbon dioxide.

As a routine procedure each gas sample was measured in at least two different counters at pressures in the range of 30 to 76 cm Hg. Each sample was usually counted for a period long enough to assure a statistical uncertainty of no more than 1% in the radiocarbon activity. The sensitivity of the counters was set at about 0.9 kev, using the monoenergetic x-rays from an Fe^{55} source as an internal energy standard. The number of undetected beta particles

possessing less than 0.9 kev of energy was estimated to be less than 0.5% and was neglected. The end effect losses were experimentally determined and the measurements appropriately corrected. Although no direct experimental measurement of the wall losses were made, they were estimated to be no greater than about 1% and the correction was neglected.

Results and Errors of Carbon-14 Measurements

The results of the stratospheric carbon-14 measurements are listed in Table 2. The probable errors in the altitudes shown in column 2 are ± 2,500 feet for altitudes below about 70,000 feet and ± 5,000 feet for the higher altitudes. Where the collection occurred over a larger range of altitude than 1,000 feet, the actual range is shown. All samples were stratospheric except those marked with the letter T which were definitely tropospheric and those marked U which were of uncertain origin. In column 3 the measured carbon-14 specific activities are given in units of disintegrations per minute per gram of carbon. The measurement errors of the unmarked values are estimated to be ± 3% or less, those marked with a single asterisk are in the range ± 3 to 5%, and those marked with a double asterisk, in the range of ± 5 to 10%. Values marked with the letter F were obtained from samples collected by freeze-out trap in the field.

In a majority of samples the abundance of carbon dioxide was determined on aliquots of the compressed air and the results are shown in column 4. Examination of these measured abundances shows that about 60% of the values are between 295 and 327 ppm. About 17% of the values are higher than 389 ppm and only 0.5% are lower than 295 ppm. Comparison of the more than fifty cases where carbon-14 measurements were made for the same sample upon both field cold trap separated carbon dioxide and carbon dioxide separated from the compressed air showed that the specific activities of the field trapped samples averaged about 10% higher than those of the compressed samples. These

facts lead to the conclusion that inert carbon dioxide contamination was introduced into those air samples which were transferred by compressors into the high pressure cylinders. In view of these considerations the measured specific activities were corrected somewhat arbitrarily as follows:

1. Where both field trap and compressed air values were measured, the higher value of the specific activity was chosen, which was usually that of the trap sample.
2. No correction was made where the measured abundance was 5 and 327 ppm.
3. Where the measured abundance was between 327 and 389 ppm the specific activity was corrected by the ratio

$$\frac{\text{measured abundance}}{311}$$

4. No correction was made in the few cases where the measured abundance was less than 295 ppm on the assumption that such low values were due to sampling errors which did not affect the specific activity.
5. Samples whose measured abundance was greater than 389 ppm are considered too unreliable to be used.
6. For samples where no abundance measurement was available, the specific activity values were corrected by the following ratios representing the difference between the average measured value from the compressed air samples at each station (excluding those values greater than 389 ppm) and 311 ppm:

Minneapolis	-	1.09
San Angelo	-	1.06
Canal Zone	-	1.12
Sao Paulo	-	1.05
Sioux City	-	1.00

An investigation is being made of the C^{13}/C^{12} ratios of the carbon dioxide samples in the hope that more exact corrections may be applied to the data.

Column 5 lists what are considered to be the best values for the concentration of artificially produced carbon-14, i.e., excess over the natural cosmic ray-produced carbon-14 background, expressed in units of 10^5 atoms of carbon-14 per gram of air. The measured specific activity values were corrected for abundance variations in the manner just described and converted to units of 10^5 atoms per gram of air on the basis of a carbon-14 half-life of 5,600 and a uniform stratospheric abundance of carbon dioxide of 311 ppm. The assumed natural background is 71×10^5 atoms of carbon-14 per gram of air, corresponding to specific activity of 13 disintegrations per minute per gram of carbon.

These excess carbon-14 results are presented graphically in Figure 3 which shows the measurements in four altitude groups as a function of time at the four collection stations. The lines connecting the points, especially in time regions of few measurements, are for visual aid only. Indicated at the top of the figure are the times of known large stratospheric injections of carbon-14 by nuclear detonations. These have been taken from the

compilation of Telegadas[4]. The detonations of each country are indicated separately. In the case of the U. S. only the Pacific test series are shown. It should be borne in mind that the U.S.S.R. tests are carried out north of 40°N; the U. S. tests have been carried out at 11°N; and the U.K. tests are carried out primarily at 2°N. The length of the bars show the duration of the test series and do not necessarily bear any relationship to the amount of carbon-14 injected into the stratosphere.

STRATOSPHERIC CONCENTRATION OF TRITIUM

Tritium Sample Processing and Measurement

The recovered samples of water from the stratospheric air collections, usually one to ten milliliters in volume, were split into two fractions. The concentration of the deuterium was measured in one fraction by mass spectrometric or infra red analysis, the concentration of the deuterium in the original tracer water having been determined previously. About 0.5 to 0.75 milliliters of the second fraction was reduced to hydrogen gas by magnesium and the tritium content of the gas measured, using a geiger counter surrounded by steel shielding and anticoincidence circuitry. The majority of the samples had counting rates at least one order of magnitude greater than background.

The total tritium collected was obtained by multiplying the tritium to deuterium ratio in the analyzed samples by the total deuterium added as tracer at the time of collection.

The volume of air collected was estimated by measuring the total number of revolutions of the blower which had been calibrated under simulated conditions and by photographing the inflated collection bag to estimate its dimensions. The mass of air samples was calculated from the density of air at the collection altitude.

Results and Errors of Tritium Measurements

The concentration of tritium per gram of air may be ascertained even though water is added or subtracted indiscriminately prior to the laboratory separation into the two fractions, provided that the added water contains no appreciable tritium or deuterium (any tropospheric water would produce no significant error). However, the tritium to hydrogen ratio in the stratosphere is not determined by this method. It can only be inferred from the water vapor content of stratospheric air, which is poorly known.

Following is an evaluation of the errors associated with the tritium measurements. The amount of tracer added to the collection of air is estimated to be accurate to about $\pm$ 1 %. The deuterium concentrations are accurate to $\pm$ 4 %. Errors in the measurement of tritium amount to about $\pm$ 10 %; about half is attributable to statistical counting errors and half to calibration errors. The tracer deuterium oxide contained less than 250 disintegrations per minute of tritium per gram. This was normally only about 5 % of the total tritium in a sample and, therefore, introduced only a small correction.

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TABLE 3

TRITIUM CONCENTRATIONS IN 1955-1956 IN THE STRATOSPHERE ABOVE MINNEAPOLIS, MINNESOTA

Collection Date	Altitude, 10^3 ft	Tritium, 10^5 Atoms/Gram Air
30 Nov 1955	59	78
4 Jan 1956	59	62
26 Oct 1955	69	43
19 Jan 1956	70	72
15 Jun 1955	76	82
11 Aug 1955	78	140
23 Sep 1955	77	115
10 Oct 1955	80	89
18 Oct 1955	80	38
26 Mar 1956	94	86
30 Aug 1956	90	107

TABLE 4

TRITIUM CONCENTRATIONS IN 1957—1958 IN THE STRATOSPHERE ABOVE MINNEAPOLIS, MINNESOTA

Collection Date	Altitude, 10^3 ft	Tritium, 10^5 Atoms/Gram Air
28 May 1957	49	11
27 Jun 1957	50	25
11 Jul 1957	50	9
6 Mar 1958	47	27
9 Apr 1958	47	42
16 Aug 1957	71	118
24 Aug 1957	65	107
26 Oct 1957	65	111
30 Nov 1957	64	89
21 Dec 1957	64	123
10 Jan 1958	64	89
20 Feb 1958	64	69
7 Jun 1958	62	58
20 Jun 1958	61	85
20 Jun 1957	76	71
15 Jul 1957	77	107
22 Aug 1957	82	59
22 Jan 1958	78	63
7 Feb 1958	77	71
25 Mar 1958	81	73
15 May 1958	78	67
17 Jun 1958	77	152
25 Sep 1957	89	124
5 Nov 1957	91	61
19 Dec 1957	88	99

The method of determining the volume of air collected is estimated to have a standard error of about ± 5 %. However, the density must be known to convert the volume to mass of air and, due to uncertainties in the absolute altitude of the collection, the mass of air collected is not known to better than ± 15 % below 70,000 feet and ± 25 % above 70,000 feet. Thus, the error in determining the mass of air containing the tritium is the predominant error.

Combining all the sources of error, it is estimated that a single determination of the tritium concentration should be accurate to ± 30 % with greater accuracy at the lower levels of the stratosphere.

A few early results were obtained in the period between June, 1955, and August, 1956, and are listed in Table 3. In these early collections, tracing was performed by adding deuterium oxide to the collection bag before launching the balloon. The error associated with these measurements may be somewhat larger than the errors associated with similar measurements made during the period 1957-1958 obtained by the collection method described above. The latter results are given in Table 4.

DISCUSSION OF RESULTS

General Comments

Figure 3, showing the excess of carbon-14 at the four locations as a function of time, shows a different pattern at the different altitudes. The excess carbon-14 values are small at the lowest altitudes (approximately 50,000 feet) and show little fluctuation with time. On the other hand, the data at the higher altitudes show large excess carbon-14 concentrations

and marked variability. Some of this variability may be due to experimental errors. However, several striking peaks, e.g., those at the Canal Zone at 65,000 to 70,000 feet in September, 1956, and July, 1958, are closely related to known injections. On the other hand, the large peaks at Minneapolos at 80,000 feet in December, 1954, and at Sao Paulo at 90,000 feet in October, 1955, 6 and 16 months after United States tests in the Marshall Islands, indicate a lack of homogeneity of the stratosphere long after the injection of the carbon-14 has occurred.

The concentrations at Minneapolis and San Angelo in the northern hemisphere are greater than at Sao Paulo in the southern hemisphere. Broecker and Walton[7] also found higher carbon-14 concentrations in northern than southern hemisphere tropospheric air.

A final observation from Figure 3 is the higher average values at Minneapolis and San Angelo than at the Canal Zone at almost all altitudes and times covered by this study. This is particularly striking in view of the large injections by the United States in the latitude closest to the Canal Zone. The significance of this observation will be discussed below.

Stratospheric Inventories[5]

The data permit estimates of the stratospheric content of radiocarbon produced by nuclear weapons. In computing these inventories, charts such as Figure 4 were prepared from concentrations averaged over six months intervals centered on 1 January and 1 July. The stratospheric content is found by graphical integration and is given in Table 5. It is felt that the errors in these numbers are no greater than $\pm$ 30%.

TABLE 5

Stratospheric Content of Artificial Radiocarbon

Date	Radiocarbon Content, 10^{27} Carbon-14 Atoms
1 July 1955	8.6
1 January 1956	8.0
1 July 1956	5.6
1 January 1957	6.6
1 July 1957	7.4
1 January 1958	6.1
1 July 1958	8.4

Münnich and Vogel[6] have estimated that there were about 4.4×10^{27} artifically produced carbon-14 atoms in the troposphere, the biosphere and the surface layers of the oceans in mid-1957. Broecker and Walton[7] estimate the same number to be 4.8×10^{27} carbon-14 atoms in March, 1958. Correcting these numbers to 1 January 1957, using an average of the growth curve from the two hemispheres given by Broecker and Walton to January, 1957, gives about 3.2 and 2.4×10^{27} atoms respectively. The same figures corrected to 1 July 1958, are 6.8 and 5.2×10^{27} carbon-14 atoms. Since Broecker and Walton have more reliable estimates of the oceanic content, numbers near the lower part of the range are probably to be preferred. The total content in the stratosphere, troposphere, biosphere and oceans was about 9.0×10^{27} carbon-14 atoms on 1 January 1957 and about 14×10^{27} carbon-14 atoms on 1 July 1958. (Libby[8] suggests that some carbon-14 may fall back to the ground or sea as calcium carbonate. This local fallout of carbon-14 is not included in the above inventories). The 1 January 1957 inventory agrees with Libby's estimate[8] of about 10×10^{27} atoms derived from the

production of carbon-14 from nuclear devices.

The observed inventory of 9.0×10^{27} carbon-14 atoms on 1 January 1957 was produced by a total of 89 megatons of nuclear explosives[9]. During the period 1957-1958 an additional 85 megatons[9] were detonated. However, a smaller fraction (30% vs. 85%) was fired at the ground in these later years. For this reason, the increment in 1957-1958 is estimated as roughly 15×10^{27} carbon-14 atoms or 50% more than the pre-1957 production. The total, about 25×10^{27} carbon-14 atoms, is the best estimate from available data of the total number of artificial radiocarbon atoms produced up until the 1958 suspension of atomic tests.

The fate of artifically produced carbon-14 is of importance in considering the biological hazards from atomic tests. According to Broecker and Walton[7] the artificial carbon-14 content of the northern hemisphere troposphere had increased by 17% by mid 1958. If the 25×10^{27} carbon-14 atoms produced artificially to the present were mixed throughout the world atmosphere only, the total tropospheric concentration of carbon-14 would be one and three-quarters times the natural cosmic ray-produced concentration. However, it is not likely that this total will exceed one and one-half times the natural concentrations because of uptake by the oceans. Continued mixing[10] with the surface layers of of the oceans will reduce the artificially produced carbon-14 in the atmosphere from the peak value to a world-wide average of about one and one-third times the natural value. The bulk of the exchangeable carbon reservoir lies in the deep oceans where there is over 50 times more exchangeable carbon than in the atmosphere. The mixing between the surface layers of the ocean and the deep ocean probably takes place over a period of several hundreds of

years. Thus, it is estimated that mixing of the artificial radiocarbon with the entire global reservoir over many tens or hundreds of years will reduce the artificial radiocarbon increment from nuclear tests carried out to the present date to below 1% of the natural background. The biological significance of increases in the carbon-14 content has been discussed by Leipunsky[11], Pauling[12] and Totter et al[13].

Some Meteorological Comments

The carbon-14 measurements afford a remarkable opportunity to study stratospheric motions. The radiocarbon observations pre-date the stratospheric measurements of particulate fission products[14]. The carbon-14 in the form of gaseous carbon dioxide is a better tracer than the particulate fission products because there is little likelihood of separation from its associated air mass by gravitational settling or other mechanisms. Only a few of the meteorological interpretations of the data are presented below; a more complete analysis will appear in a later publication.

Figure 4 depicts the distribution of artificial radiocarbon as measured during the period from April through September, 1955. The analysis north of 45°N and south of 23°S is subjective. This period was chosen for discussion because all significant stratospheric injections prior to this date occurred at 11°N. For all practical purposes they originated from only two test series, the fall of 1952 and the spring of 1954. The July, 1955, cross section, Figure 4, is based on samples collected over one year after the second and larger injection.

Some of the significant features of the figure are a) the greater concentrations at the same altitudes at the San Angelo and Minneapolis

locations than at the Canal Zone and b) higher concentrations at San Angelo, Minneapolis and the Canal Zone than at Sao Paulo, except for the 90,000 foot levels for which there are very few measurements. There appear to be two possible explanations of the distribution in Figure 4 from a source which originated closest in latitude to the Canal Zone.

The first explanation assumes that the transfer of matter in the stratosphere takes place only by diffusive mixing along the gradient of concentration. Since the Canal Zone is close to the latitude of the source, the highest concentration on such a theory must always be present at this observing point relative to the other three stations. But, since the data indicate otherwise, namely, that the Canal Zone has lower concentrations level for level than at San Angelo and Minneapolis, it is necessary to locate the highest concentrations above the altitude of the measurements, that is, above 90,000 feet. From these hypothetical high concentrations over the Canal Zone the radiocarbon mixes laterally either horizontally or along surfaces which slope gradually downward toward the poles. If the former, then vertical mixing is assumed to become more intense at the latitudes of the other stations. North-south mixing must be slower across the equator to account for lower concentrations at Sao Paulo than San Angelo or Minneapolis. The diffusion explanation may be reasonable since several powerful nuclear explosions were known to have risen beyond 90,000 feet and, in general, higher concentrations are observed at increasing altitudes at all locations. It may be objected to on the grounds that the greatest lateral extent of the visible clouds, even for those which rose very high, may have been below 90,000 feet although the gases could be concentrated at the top of the mushroom. Further, high values

at Minneapolis in December, 1954, appear at 80,000 rather than 90,000 feet. Finally, it is always unsatisfactory to explain something by unknown data just beyond the reach of observations.

The alternate explanation follows the Brewer-Dobson[15] model, as interpreted by Stewart[16] and Machta[17]. Air is presumed to rise very slowly into the equatorial stratosphere from the troposphere; then drift upward and poleward. Each hemispheric branch is approximately symmetrical with respect to the geographical equator. Later, air descends into the lower stratosphere in the temperate and/or polar zones. In this picture, the radiocarbon injections can take place below 90,000 feet. During the year following the 1954 tests, the northward drift bodily carried peak concentrations poleward in the northern hemisphere leaving much smaller concentrations at the Canal Zone. Turbulent mixing is present in the stratosphere but the transport is dominated by the circulation. Horizontal mixing across the equator brought a small amount of radiocarbon into the southern hemisphere for transport to the upper levels over Sao Paulo by the southern hemisphere circulation. This explanation is supported by the continued decrease of concentrations at the higher stratospheric altitudes over the Canal Zone until the summer of 1956 when new equatorial injections took place.

Another meteorological item of current interest is the residence time of stratospheric air masses before mixing with the troposphere. It has often been assumed that first order kinetics can be applied to this exchange mechanism, i.e., that the amount of a tracer removed from the stratosphere is always a fixed proportion of the stratospheric inventory. It is

implied in first order kinetics that the reservoir (in this case the stratosphere) is thoroughly mixed on a time scale shorter than that of the removal process. The non-homogeneous stratospheric distribution over a year after the injection (Figures 3 and 4) argues strongly against a fast mixing hypothesis. However, there is interest in knowing what fraction of the carbon-14 came out of the stratosphere during the early years. It should be noted that this fraction need not be the same for later years or for the first few years following an injection into the stratosphere at other latitudes and altitudes. Most of the carbon-14 prior to 1957 was added at 11°N.

Calculation of the stratospheric removal rate from differences in the total stratospheric contents at successive times is unreliable due to the inaccuracies in the inventories and the uncertain magnitudes of the injections of carbon-14 occurring during the periods considered. Instead, an alternate method is used which depends only on the relative source strengths and an inventory at a single time.

By 1 January 1957, the total artificial radiocarbon inventory was about 9.0×10^{27} carbon-14 atoms, of which 6.6×10^{27} were still in the stratosphere. The fraction of the total remaining in the stratosphere can be explained using known times and relative magnitudes of stratospheric injections (taking into account local fallout) and an exponential removal rate corresponding to about 17% per year. The mean stratospheric residence time on this basis is about 6 years (a half time for removal of 4 years).

A mean residence time in the stratosphere can also be calculated from the average stratospheric carbon-14 inventory and Broecker and Walton's growth curve[7] for the troposphere. The stratospheric inventory is constant,

almost within experimental error, at 7.2×10^{27} carbon-14 atoms during the period 1 July 1955 to 1 July 1958 (see Table 5). The average rate of increase in carbon-14 in the troposphere during this period was 1.2×10^{27} atoms per year[7]. A very rough estimate of the average rate of uptake of the artificial carbon-14 by the oceans during the same period is 0.3×10^{27} atoms per year. This is based on a mean tropospheric content of 2.1×10^{27} atoms and a removal rate of one-seventh per year[10]. Thus, about 1.5×10^{27} artificially produced carbon-14 atoms were removed from the stratosphere each year, corresponding to a mean residence time of slightly less than five years.

These residence times, about 5 years, are shorter than Libby's earlier estimate[18] but are closer to the recent computations of the Department of Defense[19], Libby[20] and Machta and List[21].

The uncertainty in the residence time is directly proportional to the uncertainty of the stratospheric inventory and depends to a lesser extent, on the rate of uptake by the oceans. Further, it is assumed that all of the injections enter the stratosphere. A small error is made because some radiocarbon from weapons tests is inserted directly into the troposphere.

Comparison of Tritium and Carbon-14 Measurements

Figure 5 is a plot of the total tritium against the excess of carbon-14 concentration at Minneapolis. It is evident that there is a positive correlation between the tritium concentration and the excess radiocarbon. On the assumption of a constant tritium to carbon-14 ratio from contributing nuclear explosions, the data can be used to calculate the natural tritium content of the stratosphere. The tritium concentration corresponding to zero excess carbon-14 is the natural tritium background value. Although only the 1957-1958 points near the 50,000 foot level yield a statistically

significant background value, 7×10^5 ($\sigma = 3.5 \times 10^5$) tritium atoms per gram of air, the entire body of 1957-1958 data gives a value consistent with this. If this concentration is assumed to exist throughout the stratosphere, then there are approximately 6×10^{26} naturally occurring tritium atoms in the entire stratosphere. Assuming that the mean stratospheric residence time is 5 years for natural tritium and that two-thirds of the natural production takes place in the stratosphere (as would be the case for cosmic ray production), the 6×10^{26} tritium atoms lead to an average world-wide natural production rate of 1 tritium atom per square centimeter per second, in good agreement with recent estimates summarized by Begemann[22].

The tritium concentrations expressed as atoms per gram of air can be converted to tritium atoms per 10^{18} hydrogen atoms by estimating the stratospheric moisture content. The frostpoint in the stratosphere is believed to lie in the range of -65°C to -80°C. Thus, the 50,000 foot background tritium concentration of 7×10^5 tritium atoms per gram of air would correspond to between 4×10^5 and 4×10^6 tritium atoms per 10^{18} hydrogen atoms. For comparison, pre-1954 rains in Chicago contained 3 to 34 tritium atoms per 10^{18} hydrogen atoms[23].

The good correlation between the excess carbon-14 and tritium permits one to estimate the number of tritium atoms associated with each carbon-14 atom produced by weapons tests. Assuming that the ratio of tritium to carbon-14 atoms, 0.4, based on all of the 1957-1958 data was the same at other locations than Minneapolis, the stratospheric inventory of excess tritium on 1 January 1958 was 2.4×10^{27} atoms, or about four times the natural content of the stratosphere. The rapid removal of tritium from the troposphere by precipitation puts most of non-stratospheric tritium in the oceans.

Because of inadequate oceanic sampling, no attempt is made to obtain a complete inventory of weapons produced tritium.

June 1959

References and Notes

(1) The collection equipment was developed by General Mills, Inc. Samples were collected by General Mills, Inc. during the early period of sampling and subsequently replaced by Headquarters Command, U. S. Air Force. We gratefully acknowledge the assistance of the following General Mills Mechanical Division personnel: J. W. Swisher, D. Crowe, W. Borgeson, R. Dungan, J. Smith, R. Mautner, D. Dietsche, J. Gravelle as well as H. Demerest and R. Stuart for their scientific evaluation of the flights.

(2) C. D. Keeling, Geochim. et Cosmochim. Acta, 13, 322 (1958); I.G.Y. Bulletin Number 20, Trans. A.G.U., 40, 57 (1959).

(3) The radiocarbon measurements were carried out at the Argonne National Laboratory by personnel of the Chemistry Division. James Gray, Jr. was chiefly responsible for the development and operation of the counting system. A. S. Quattrochi and S. J. Rymas conducted most of the measurements. Their assistance is gratefully acknowledged.

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(5) The contribution of Robert J. List of the U. S. Weather Bureau to the meteorological analysis of the data is acknowledged.

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FIGURE LEGENDS

Figure 1. Schematic drawing of balloon train used in the collection of the stratospheric radiocarbon, carbon dioxide and tritium samples.

Figure 2. Sampling train used in the collection of stratospheric air during descent. See Figure 1 for identification of visible parts of the train. The large collection bag has not yet transferred its air to the armored bag which hangs limply above it. The larger package at the bottom of the train is the filter apparatus which collects particulate stratospheric radioactivity. It is the size and shape of an ash can.

Figure 3. Excess carbon-14 as a function of time at various altitudes and latitudes. Bars at top of figure indicate large stratospheric injections of radiocarbon by nuclear tests.

Figure 4. Altitude-latitude cross section of the atmosphere showing the mean radiocarbon distribution as of 1 July 1955. Concentrations in 10^5 atoms per gram of air are indicated near points identifying the altitude. Numbers in parenthesis show the number of samples from which the mean concentration was computed. Thin lines are isolines of carbon-14; heavy lines indicate the position of the tropopause.

Figure 5. Relationship between total tritium and excess carbon-14 in the stratosphere.

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Table 2

Stratospheric Radiocarbon Concentrations

In column 2 the letter T indicates the sample was definitely collected in the troposphere. The letter U indicates uncertainty whether sample collected was in the stratosphere or troposphere. Unmarked values are stratospheric.

In column 3 a single asterisk indicates a measurement error of 3 to 5 %, a double asterisk a measurement error of 5 to 10%. Unmarked values have measurement errors less than 3%. Values marked with the letter F indicate carbon dioxide separated in the field with a freeze-out trap.

A carbon half-life of 5600 years and atmospheric abundance of carbon dioxide of 311 ppm were used to calculate values in column 5. After correction for variation in CO_2 abundance (see text) a natural background of 71 x 10^5 atoms/gm air was subtracted to give excess carbon-14.

Minneapolis, Minnesota (45° N. Latitude) 1

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1953				
24 Sept.	81	16.8*	--	29
9 Oct.	82	17.8	--	36
5 Nov.	82	26.8**	--	89
12	64	22.1*	--	61
17 Dec.	53	16.1**	--	25
23	64	15.1*	--	19
1954				
28 Jan.	80	23.9*	--	72
28	52	15.0*	--	18
28	65	19.5*	--	46
6 Feb.	68-66	21.8	--	59
16	79	30.8	--	113
22	47	13.3*	--	9
22 Jun.	98	27.6*	--	94
8 Jul.	82	28.6	--	100
10 Sept.	49	16.1*	--	25
22	79	36.8	--	149
15 Oct.	64	42.2	--	181
19	50	14.3*	--	14
20	79	27.3*	--	93
27	66	46.9*	--	209
2 Nov.	66	52.0	--	240
8	67	28.4	--	99

Minneapolis, Minnesota 2

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1954				
22 Nov.	95	36.1	--	145
22	66	33.7	--	131
30	79	104.6	--	554
4 Dec.	51	13.5*	--	10
6	79	122.2	--	658
10	65	34.1	--	133
19	65	47.6	--	213
27	61	31.8	--	128
27	71	79.3*	--	402
29	66	50.0	--	228
1955				
6 Jan.	49 U	27.5*	--	94
6	73	68.7	--	339
29	66	30.8	--	113
30	80	56.5	--	267
8 Feb.	71-68	66.4	--	326
8	65	38.3	--	158
14	59	29.0	--	102
1 Mar.	66	60.6	--	291
2	49 U	15.1*	--	19
9	92	23.0	--	66
16	77	67.8	--	333
16	59 U	20.8	--	53

Minneapolis, Minnesota 3

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1955				
28 Mar.	70	73.5	--	368
2 Apr.	60 U	22.2	--	62
7	50	23.5	--	70
25	70	30.0**	--	108
25	78	41.9	--	180
6 May	49-47 U	13.2**	--	7
11	77	56.9	--	269
18	76	68.6	--	339
20	70	61.4	--	295
14 Jun.	61-58	26.7	--	88
15	76	62.8	--	304
23	71	61.2	--	294
7 Jul.	50	14.5*	--	15
18	76	70.4	--	350
20	59	17.8	--	36
8 Aug.	68	43.4	--	188
10	60	17.6	--	34
11	78	42.1 F	--	160
1 Sept.	57	25.4	--	81
7	65	32.6	--	124
23	77	71.7 F	--	322
24	59	24.7	--	76
28	48 U	15.8*	--	24

Minneapolis, Minnesota 4

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess $C^{14}.10^5$ Atoms C^{14}/gm air
1955				
10 Oct.	80	55.3 F	--	232
13	58	31.5	--	118
18	80	56.1 F	--	236
21	48 U	13.7*	331	9
26	69	35.4* F	--	123
28 Nov.	50	18.7* F	--	31
30	59	48.6* F	--	195
30	69	31.4**	--	116
5 Dec.	70	37.6 F	--	135
6	48	12.9** F	--	33
9	56 U	31.6	--	118
9	69	33.8	--	131
12	49	17.1	316	23
21	83	54.6 F	--	228
1956				
4 Jan.	59	24.5 F	--	63
12	50	25.4 F	--	68
13	82	51.0* F	--	208
19	70	55.2** F	--	231
30	59 U	32.0	--	120
7 Feb.	68	45.6	323	179
18	81	67.3	294	298
27	91	85.1 F	--	395

Minneapolis, Minnesota 5

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1956				
28 Feb.	52	23.5	306	58
29	50	16.1** F	--	17
8 Mar.	48.	23.4 F	--	57
16	66.	35.4	312	123
26	94	59.6** F	--	255
30	83	70.9 F	--	317
9 Apr.	95	40.5	313	151
10	68	37.8	306	136
30	49.	18.6	393	--
7 May	66.	36.8	307	131
16	83	53.2	240	220
21	49	17.2	352	37
27	92	58.0	326	247
5 Jun.	80	51.4	296	211
8	65.	14.0**	314	6
11	94	52.0	308	214
19	54.	16.4	593	--
21	68	14.2*	316	7
21	88	48.9	339	222
24	80	41.9	326	159
2 Jul.	80	41.8	282	158
6	65	39.4	307	145
12	50	17.5	325	25

Minneapolis, Minnesota 6

Collection Date	Altitude, 10^3 feet		Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1956					
16 Jul.	90		38.1	443	--
1 Aug.	71-61		28.3	573	--
5	50		15.8	595	--
13	80		43.1	412	--
30	90		63.5 F	--	277
12 Sept.	65		31.9	305	104
14	90		54.8	349	265
18	80		46.6	289	184
23	50	U	18.3	282	29
2 Oct.	52	U	25.9	354	91
12	66		32.6	312	108
16	84		55.6	336	259
19 Nov.	80		52.4	395	--
23	66		12.8	314	-1
27	48		13.3	331	7
13 Dec.	52	U	31.8	328	113
20	83		39.6	408	--
1957					
10 Jan.	67		69.0	311	307
29	90-85		65.1	324	286
6 Feb.	50	U	14.9	529	--
13	82		63.3	308	274
19	67		57.5	322	244

Minneapolis, Minnesota 7

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1957				
9 Mar.	68	59.4	356	300
17	47	29.5	351	112
30	83	47.1	341	212
10 Apr.	84	43.4	322	167
14	67	55.5	460	--
15	48	28.0 F	--	82
25	48 U	26.4 F	--	74
27 May	63	28.1	392	--
28	49	16.2* F	--	18
29	73	46.9	308	186
19 Jun.	92	37.2	365	169
20	76	50.4 F	--	205
27	50	24.1 F	--	61
11 Jul.	50	15.4	--	13
11	62	33.7 F	356	141
15	77	57.2 F	--	242
19	85-82	48.5	363	240
23	65	32.5	348	128
2 Aug.	49 U	11.3*	370	3
10	90	38.6	376	183
16	71	59.2 F	--	253
22	82	50.3 F	--	205
24	65	53.9 F	--	224

Minneapolis, Minnesota 8

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1957				
4 Sept.	46	16.2	334	27
6	77	47.1	407	--
25	89	58.0 F	--	247
2 Oct.	79	46.5	316	184
2	49	16.6	342	29
26	65	62.8* F	--	273
29	90	50.1 F	--	203
5 Nov.	91	47.9	--	214
7	108-105	41.6	333	173
25	79	50.7	327	207
26	50	16.7	326	20
30	64	51.1 F	--	209
4 Dec.	47	21.0 F	--	44
12	81	49.4 F	--	200
19	86	51.5 F	--	211
21	64	45.1 F	--	176
1958				
8 Jan.	48 U	15.2	328	17
10	64	47.1 F	--	187
22	78	49.1 F	--	198
31	92	40.2	369	190
5 Feb.	90-88	49.8	328	217
7	77	51.3 F	--	210

Minneapolis, Minnesota 9

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1958				
13 Feb.	46	25.5	353	88
20	64	44.9* F	--	175
6 Mar.	47	19.1	--	43
12	64	38.9	340	162
25	81	42.4 F	--	161
26	93	41.1	341	176
7 Apr.	90	44.6	--	195
8	78	47.1 F	--	187
9	47	33.6 F	--	113
16	65	48.5** F	--	195
9 May	92	45.2 F	--	177
12	48	23.2 F	--	56
15	78	38.8 F	--	142
6 Jun.	91	28.9	--	202
7	62	49.8** F	--	101
11	47 U	25.3 F	--	68
17	77	47.8 F	--	191
20	61	40.9 F	--	153

San Angelo, Texas (32° North Latitude) 10

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1955				
22 Mar.	50 U	15.9	--	21
24	62	26.8	--	85
29	71	70.7	--	339
30	74	64.4	--	303
5 Apr.	62	25.7	--	78
8	72	50.8	--	224
14	78	68.5	--	327
21	53-51	15.1	--	17
25	71	41.7	--	171
13 May	70	42.8*	--	177
14	53-50 D	16.6	--	25
16	79	72.6	--	350
17	63	20.4	--	48
23 Jun.	71	44.8	--	189
5 Jul.	77	48.7	--	212
12	61	20.2	--	47
2 Aug.	53-51	14.9**	--	16
3	70	31.1	--	109
7	59	20.7	--	49
10	78	40.1	--	162
8 Sept.	71	28.8	--	96

San Angelo, Texas 11

Collection Date	Altitude, 10^3 feet		Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1955					
9 Sept.	60		17.2*	--	29
27	77		40.6	--	164
28	93		62.2	--	290
29	93		62.7	--	293
19 Oct.	71		21.3	--	53
25	60		20.4	--	48
3 Nov.	83-80		42.7	323	163
4	71		54.1	301	225
9	50		20.8	299	43
21	62		20.1	310	39
25	81		55.8*	376	299
4 Dec.	51		13.1	377	16
7	62		25.3	382	100
10	82		48.2	329	208
12	72		37.7	331	149
1956					
25 Jan.	50	U	15.2	312	12
6 Feb.	84		56.1	325	236
20	66		29.7	310	92
8 Mar.	69		12.5*	303	-3
16	83		63.2	316	275
22	50		15.7	291	15
23	98		69.8	311	311

San Angelo, Texas 12

Collection Date	Altitude, 10^3 feet		Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1956					
4 Apr.	95		69.6	336	341
14 May	52-51		13.2	320	1
16	68-63		40.7	617	--
17	84		58.1	314	247
8 Jun.	50	U	15.7**	313	15
18	65		28.9	327	87
19	81		50.7	338	231
6 Jul.	52		16.0	398	--
8	83		44.5	351	204
18	66		28.3	373	115
22	93		51.8	379	275
6 Aug.	47	T	14.4	556	--
7	65		38.1	619	--
9	84		41.5	483	--
11	94		57.8	331	266
25	94		52.2	328	231
5 Sept.	80		48.1	405	--
7	94		23.6	475	--
8	50	T	14.2	388	26
11	65		27.1	333	87
5 Oct.	96		44.8	374	224
11	65		32.1	480	--
16	79		34.2	1880	--

San Angelo, Texas 13

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1956				
22	47 T	13.3	690	--
6 Nov.	94	53.6	312	223
13	66	38.2	312	138
16	44	13.4*	329	6
17	77	51.7	298	212
15 Dec.	63	40.5	500	--
17	95	52.6	307	217
1957				
12 Jan.	100	44.7	427	--
17	67	42.8	381	216
1 Feb.	97	42.5	308	162
10	80	69.7	304	311
25	67-65	30.6	348	117
7 Mar.	96	46.4	338	205
12	81	68.7	340	340
18	50	13.9*	411	--
23 Apr.	81	51.2	340	235
29	66	52.9	321	219
2 May	82	65.5	310	288
3	66	43.4	294	167
19	89-87	45.0	243	176
21	49 U	13.8*	301	5
6 Jun.	91	49.5	311	200

San Angelo, Texas

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14} Atoms $C^{14}/gm\ air \times 10^5$
1957				
10 Jun.	67	44.2	296	171
12	48 U	15.7*	326	15
19	82	57.4	343	275
7 Jul.	88	56.7	392	--
9	67	36.3	306	128
11	85-78	55.9	296	235
13	48	14.0	302	6
6 Aug.	65	37.7	364	171
7	91	38.2	483	--
9	82-78	58.4	308	249
20	50	14.8	418	--
4 Sept.	90	53.2	333	241
6	81	40.1	306	149
11	65	24.4	383	94
13	49	13.7	376	20
1 Oct.	50	10.1*	402	--
3	91	27.7	475	--
4	83	54.1	323	225
5	65	24.4	337	74
2 Nov.	90	57.7	311	245
14	48	19.5	309	36
20	84	39.6	309	146
26	66	46.9	310	186

San Angelo, Texas 15

Collection Date	Altitude, 10^3 feet		Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1957					
2 Dec.	82-80		54.3	313	226
4	49	T	13.2	306	1
7	90		55.4	315	232
10	67		40.0	320	148
1958					
7 Jan.	81-79		55.6	--	252
8	90		46.5	348	214
9	50		15.5	349	24
15	62		42.7	331	178
1 Feb.	50	U	13.5*	324	3
2	92		49.2	330	215
7	65		40.5	309	151
15	80		49.7	313	201
3 Mar.	92		43.0*	311	165
7	80		49.4	314	200
9	67		41.7	308	157
10	51	U	19.2	309	34
1 Apr.	92		42.3	317	161
3	65		28.9	315	87
7	82		47.6	313	190
8	49		14.8	318	10
3 May	48	U	20.2*	318	40
4	66		36.5	317	129

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San Angelo, Texas 16

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1958				
7 May	92.	45.7	312	179
10	49.	26.0	314	71
19	81.	53.3 F	--	221
3 Jun.	81.	47.2	--	204
5	89.	48.6 F	--	168
7	65.	47.2	--	204
8	52.U	13.5** F	--	3
2 Jul.	82.	46.7 F	--	185
3	67.	41.3 F	--	155
12	50.U	24.0 F	--	60
18	89.	45.3	--	192
1 Aug.	50.U	16.8*	--	27
2	92.	44.7	--	189
3 Aug.	66.	38.8	--	155
5	81	52.7 F	--	218
1 Sept.	90.	47.4 F	--	189
3	80.	49.2 F	--	199
4	51.U	17.7 F	--	26
9	66.	38.0 F	--	137

Canal Zone, Panama (9° North Latitude) 17

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1955				
30 Mar.	75	29.7	--	112
31	50-48 T	12.3*	--	4
11 May	69	21.5	--	61
12	63	12.1*	--	3
27	79	40.3	--	177
11 Jun.	51 U	13.4**	--	11
13	61	13.1	--	10
29	79	36.3	--	152
30	70-69	19.2	--	47
7 Jul.	78	32.3	--	127
18	51 T	14.0	--	15
28	62	14.0*	--	15
30	70	13.7**	--	13
6 Aug.	77	27.5	--	98
9	60	17.8	--	39
26	52	13.4	--	11
10 Sept.	77	16.6*	--	31
13	70	12.9*	--	9
22	94-91	46.5	--	215
18 Oct.	92-89	44.2	--	200
28	77	26.3	--	90
30	61	14.9*	--	21
2 Dec.	83	26.1	317	72

Canal Zone, Panama 18

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1955				
11 Dec.	51 T	3.2**	1500	--
14	71	18.2	367	47
1956				
20 Jan.	50 T	11.1*	336	-5
21	62	15.4	325	13
12 Feb.	62	18.6	325	31
3 Mar.	52 T	12.0*	321	-5
4	71	11.7*	355	2
14	51	11.7*	345	0
28	80	22.3	309	51
4 Apr.	52 T	11.2	341	-4
5	68	19.7	317	37
9	82	18.0	309	28
10	93	20.7	307	42
6 May	50 T	12.2	368	8
15	81	17.8	396	--
22	61	16.6	422	--
1 Jun.	51 U	12.5*	351	6
11	66	16.7	439	--
15	82-80	19.2	716	--
6 Jul.	55	11.2**	365	1
7	67	23.4	326	57
1 Aug.	67	32.7	336	122

Canal Zone, Panama 19

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1956				
7 Aug.	54 T	12.2*	301	-4
4 Sept.	52	12.7*	329	3
6	69-66	91.3	343	480
4 Oct.	97-90	27.5	534	--
15	67	37.1	381	178
16	54	11.0**	338	-6
21	87-83	35.3	295	122
1 Nov.	51 T	11.9*	348	2
1	70	50.4	321	205
19	92	29.2	350	109
27	81-79	34.7	330	131
1 Dec.	52 T	10.7*	382	1
4	93-88	29.8	359	117
10	67	24.1	372	87
1957				
20 Feb.	84-82	47.5	361	231
21	51 T	11.3*	352	-1
22	66	17.7	343	36
1 Mar.	77	28.2	552	--
3	65	12.3**	377	10
4	47 T	3.9**	459	--
7	91-87	29.1	341	103
4 Apr.	82	57.1	388	319

Canal Zone, Panama 20

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1957				
11 Apr.	66-64	15.3*	296	13
13	50 T	10.3*	374	-4
4 May	65	10.9	351	-3
7	49 T	9.5	353	-12
10	78	43.6	316	167
22	65	11.2**	378	3
7 Jun.	81-79	47.3	361	230
9	65	22.4	309	52
1 Jul.	49 U	12.5*	355	7
14	67	26.6	321	75
19 Aug.	66	23.2	368	79
20	50 U	13.2	424	--
20 Sept.	65	21.6	327	47
8 Oct.	89	48.4	324	194
21	49 T	12.9	322	0
23	67	20.4	312	40
30	80	29.4	321	90
1 Nov.	82	29.7	534	--
3	89	27.1	324	77
5	52 T	13.2	319	1
6	66	24.1	319	61
1 Dec.	46 T	12.2	319	-4
2	90-88	31.0*	363	127

Canal Zone, Panama 21

Collection Date	Altitide, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1957				
4 Dec.	66	20.9	396	--
15	73-76	27.9	323	81
1958				
2 Jan.	51 T	10.8**	334	-8
5	81	28.1	381	118
13	92	37.0	338	140
15	65	40.2	348	145
5 Feb.	67	26.2	327	73
10	82	30.7	327	97
16	93	28.9	515	--
4 Mar.	92	30.3	347	114
8	50 T	12.3**	347	4
1 Apr.	94	39.9	358	181
3	52 T	13.1*	401	--
4	81	37.6	369	173
14	65	10.0**	512	--
1 May	65	22.9	322	54
2	51 T	14.6	348	19
4	85	33.2	334	124
9	80	42.2	337	179
2 Jun.	65	24.4	328	70
6	81	45.7	380	234
8 Jul.	61	44.9	332	192
14	51 U	11.3*	459	--

Canal Zone, Panama 22

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1958				
1 Aug.	65	183.3	313	933
6	51 T	15.6	244	14
3 Sept.	65	64.6 F	--	283
8	52	14.3	--	16

Sao Paulo, Brazil (23° S Latitude) 23

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1955				
22 Mar.	61	13.4*	--	6
29	50 T	13.9*	--	9
17 Apr.	62	12.7*	--	3
26	79	25.1	--	73
27	70	17.3	--	29
28	52 T	14.3*	--	11
9 May	78	22.4	--	58
11	60	13.2*	--	1
12	50 U	12.9*	--	4
27	69	15.2*	--	16
14 Jun.	78	21.8*	--	54
15	61	12.8**	--	3
5 Jul.	79	24.2	--	69
7	71	16.0	--	21
10	62	11.2	--	-7
3 Aug.	78	21.2*	--	51
6	61	14.7	--	14
30	70	14.5	--	12
14 Sept.	60	12.9	--	4
28	90	98.0	--	493
11 Oct.	91	105.7	--	537
12	77	33.7	--	123

Sao Paulo, Brazil 24

Collection Date	Altitude 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1955				
13 Oct.	68	17.9	--	32
30	61	14.4*	398	--
1 Nov.	76	37.7	321	136
20	69	20.6	305	42
25	52 U	15.3	301	13
26	62	13.7**	317	4
2 Dec.	75-69	20.7	589	--
6	52 T	11.7*	434	--
7	82-80	39.2	306	144
8	6[illegible]	15.7	308	15
27	81	36.4	278	128
1956				
10 Jan.	62	15.6*	375	31
11	71	17.6	292	25
12	81	39.3	298	144
16	52 T	13.4**	285	2
1 Feb.	52 T	13.5	308	3
6	62	14.7	300	10
7	69	22.3	305	51
24	81	26.9	327	76
5 Mar.	80	26.2	281	73
13	52 T	12.8	276	-1
14	70	17.7	307	26

Sao Paulo, Brazil 25

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1956				
3 Apr.	83-81	21.7	380	74
26	96	33.7	399	--
27	53-50 U	12.8**	296	-1
18 May	81	18.1	298	28
19	68-65	15.6	291	14
20	91	22.0	313	50
21 Jun.	51	14.5	310	8
23	68-65	25.2*	377	96
30	80	19.3	380	59
17 Jul.	50 J	15.1	517	--
19	67-65	23.2	425	--
20	80	47.4	429	--
22	90	42.6	300	162
16 Aug.	92-90	23.7	292	59
17	82-80	37.1	308	132
18	50 T	14.7	282	10
29	68-65	26.4	310	74
11 Sept.	53-50 U	15.1	304	12
12	68-65	45.1	407	--
15	90	34.8	293	120
16	80	30.7	380	134
2 Oct.	54-50 U	13.8	326	5
4	67-65	22.7	306	53

Sao Paulo, Brazil 26

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1956				
26 Oct.	90	24.5*	344	77
29	81	50.8	322	207
30	91	37.7	301	136
1 Nov.	90	19.8	314	37
19	81	29.4	554	--
10 Dec.	90-87	26.0	317	71
12	90	27.5	332	90
21	66	21.2	331	52
1957				
18 Jan.	90	43.2	344	191
28	90	35.3	389	170
29	84-80	33.4	424	--
11 Feb.	97-90	36.1	419	--
12	83-80	32.8	--	118
16	68-65	12.8*	468	--
19	50 T	11.0*	379	2
19 Mar.	90	38.4	308	139
20	80-78	24.7	303	64
25	66	21.2	298	45
26	50-46	13.1	295	1
10 Apr.	90	35.2	413	--
25	84	38.3	308	139
26	68-66	19.0**	307	33

Sao Paulo, Brazil 27

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1957				
27 Apr.	49 T	12.8*	313	-1
14 May	65.	19.4	313	35
15	95	39.5	297	145
17	81	39.6	320	146
18	50 T	13.2	325	1
19	80	37.6*	308	135
31	80	47.0	301	186
1 Jun.	90	37.9	404	--
2	64	17.8	349	39
13	94	34.2	306	116
14	81-78	37.6	331	148
15	49 T	12.2*	410	--
9 Jul.	66	15.8	481	--
10	93	41.0	308	154
11	93	39.9	363	185
12	80-74	39.1	298	143
13	49 U	14.3*	345	16
3 Aug.	68	33.7	298	114
5	49 U	16.2*	522	--
8	80	43.3	313	166
10	90	39.7	495	--
16	89	35.4	357	152
17	90	38.5	369	179

Sao Paulo, Brazil 28

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1957				
5 Sept.	49 U	15.2*	339	20
6	65	30.2	310	94
10	80	39.3	311	144
12	81	37.4	319	134
15	87	36.1	314	127
21 Nov.	92	35.3	326	122
22	82-75	37.7	316	136
24	80	32.9	315	109
25	65	28.4	322	85
10 Dec.	82-80	30.8	323	98
12	66	32.2	320	105
14	51 U	12.7	312	-1
19	96-93	42.6	323	162
1958				
7 Jan.	79	28.5**	326	85
8	89	36.9	323	131
10	65	27.7	391	--
11	51 U	12.4*	337	3
3 Feb.	66	25.9*	314	71
9	80	39.7	304	146
10	90	37.0	316	132
5 Mar.	80	38.4	313	139
6	90	38.8	323	142

Sao Paulo, Brazil 29

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1958				
7 Mar.	80	35.4	312	128
13	66	22.9	320	54
14	50 T	12.8	308	-1
2 Apr.	52 U	15.1	310	12
3	69	34.4	325	117
4	81	33.1	316	110
5	90	34.7	314	119
9 May	65	23.0**	329	62
11	89	33.8	308	114
12	51 T	13.9**	316	5
16	88	38.6	317	140
17	80	38.7	325	151
4 Jun.	64	22.5	316	52
5	88	41.4	319	156
8	80	37.3	--	143
10	48 T	15.5	--	18
13	79	40.8 F	--	153
9 Jul.	90	36.1 F	--	127
10	63	33.3	--	120
11	80	36.3	--	138
13	52 U	16.0	--	21
5 Aug.	93	37.5*F	--	134
7	81	36.8	--	141

Sao Paulo, Brazil 30

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1958				
8 Aug.	53 T	17.8 F	--	27
9	65	39.1	--	154
2 Sept.	95	31.9	--	113
4	53 U	13.2	--	5

Sioux City, Iowa (42.5° N. Latitude) 31

Collection Date	Altitude, 10^3 feet	Observed Specific Activity dpm/gm C	Measured CO_2 Abundance ppm	Excess C^{14}, 10^5 Atoms C^{14}/gm air
1958				
5 Jul.	50 U	17.7	314	26
6	66	47.3	301	188
7	81	46.1	369	229
28	93	45.2*	334	195
2 Aug.	90-88	43.7	317	168
3	66	45.5	313	178
7	49	19.2 F	--	34
9	80	48.7 F	315	196
1 Sept.	88	44.5	329	187
1	50 U	17.6	311	25
8	62	40.3	--	150
15	83	48.0	--	192

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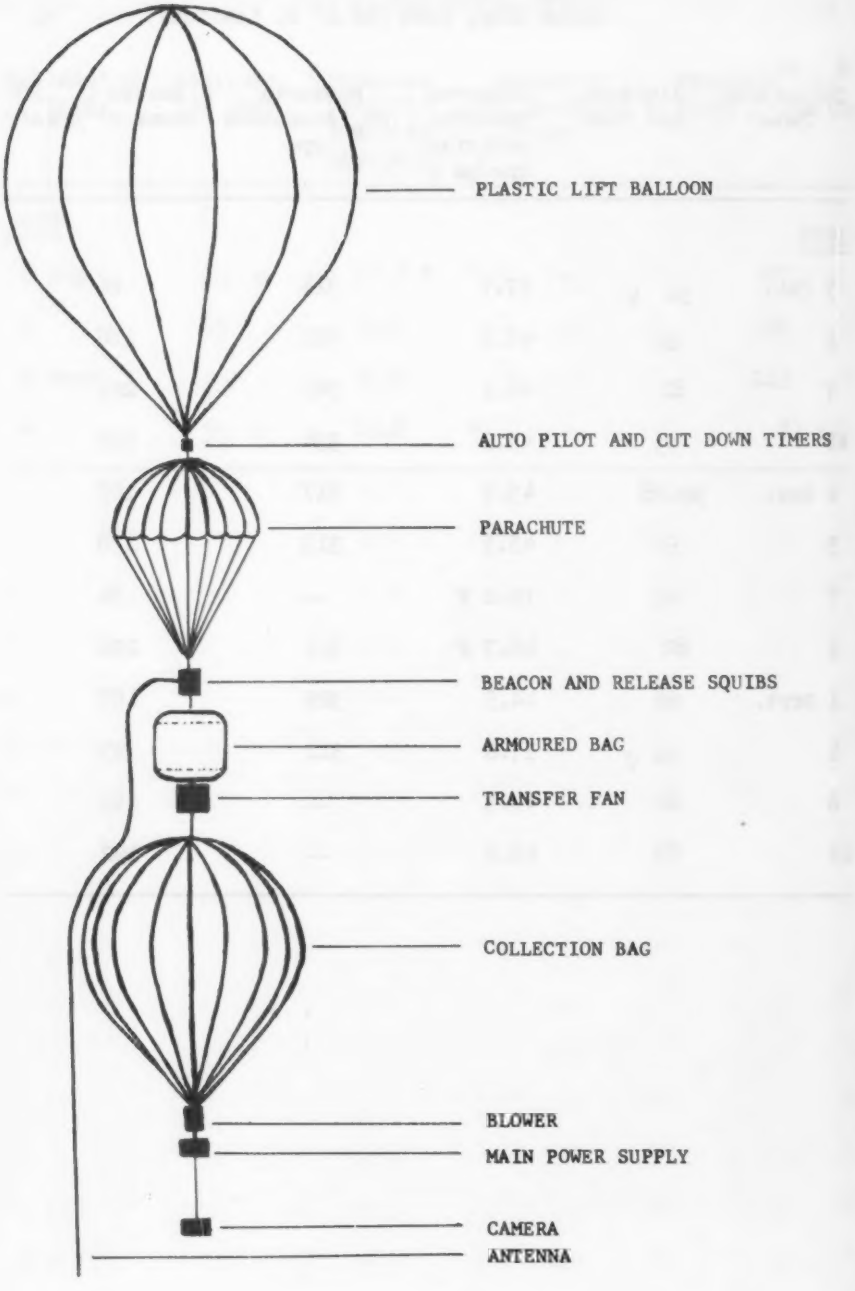
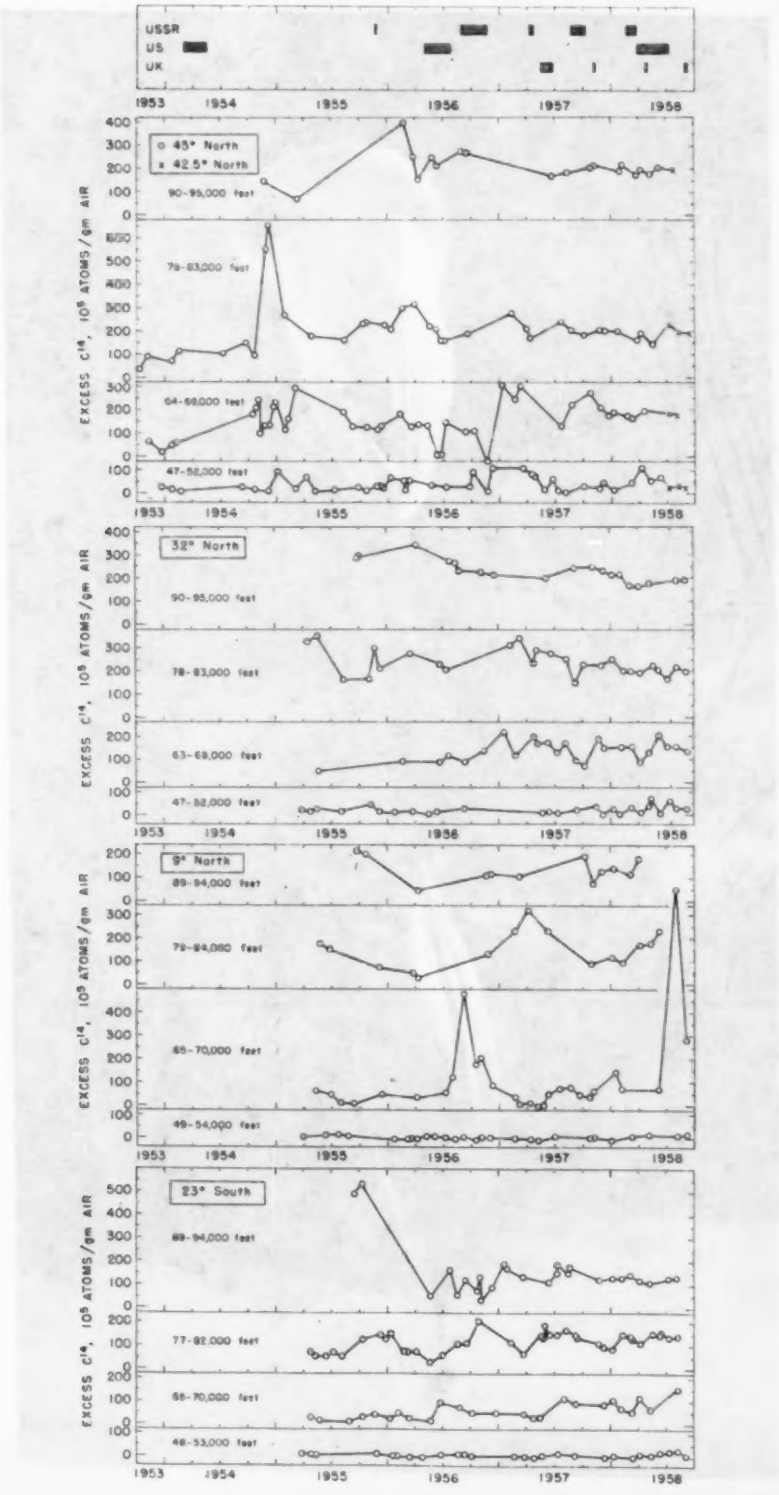
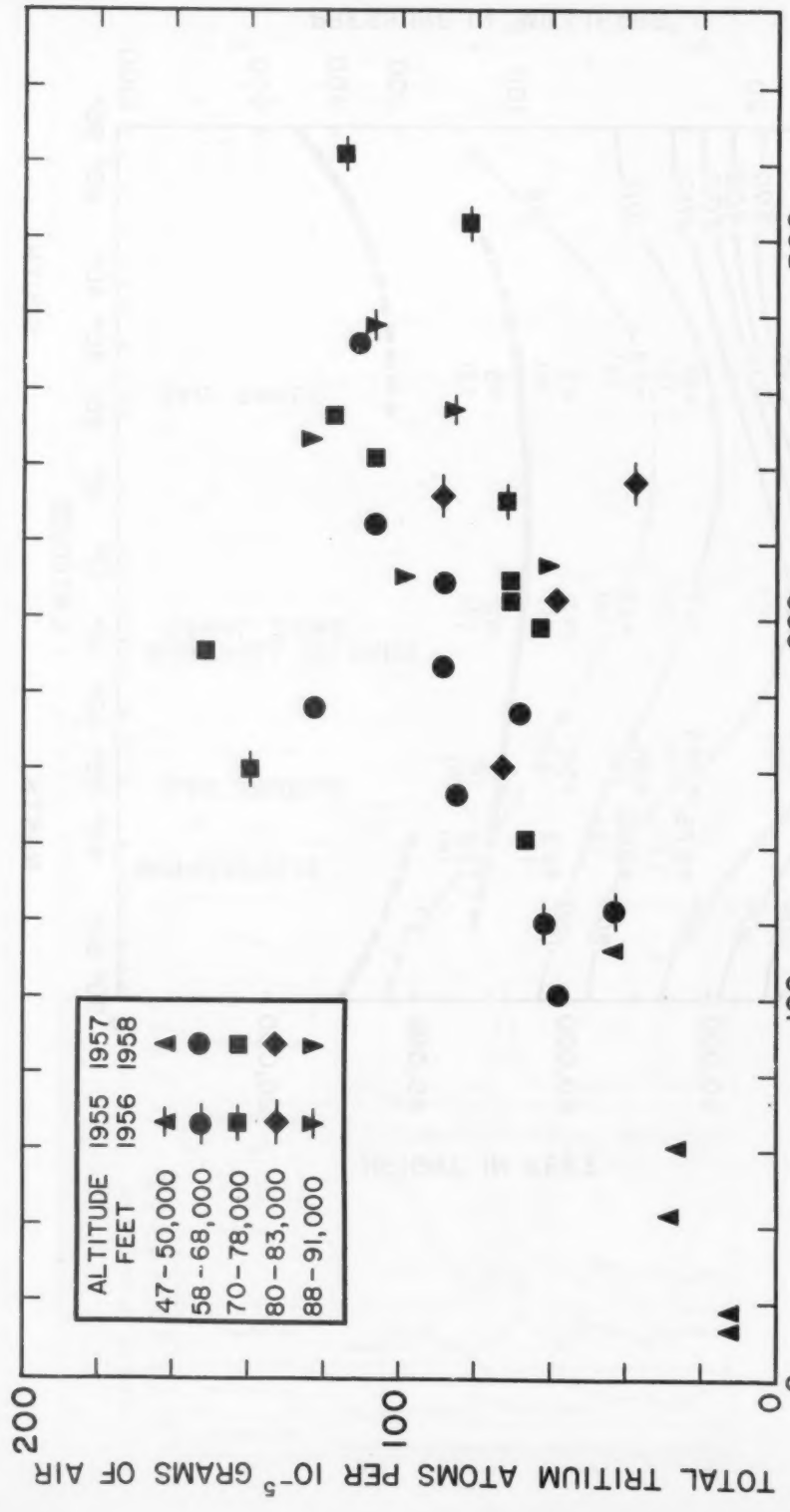

PLASTIC LIFT BALLOON
AUTO PILOT AND CUT DOWN TIMERS
PARACHUTE
BEACON AND RELEASE SQUIBS
ARMOURED BAG
TRANSFER FAN
COLLECTION BAG
BLOWER
MAIN POWER SUPPLY
CAMERA
ANTENNA


USSR
US
UK
1953
1954
1955
1956
1957
1958
45° North
42.5° North
90-95,000 feet
78-83,000 feet
64-68,000 feet
47-52,000 feet
32° North
90-95,000 feet
78-83,000 feet
63-69,000 feet
47-52,000 feet
9° North
89-94,000 feet
78-84,000 feet
65-70,000 feet
49-54,000 feet
23° South
89-94,000 feet
77-82,000 feet
66-70,000 feet
48-53,000 feet
EXCESS C14, 10³ ATOMS/gm AIR

PRESSURE IN MILLIBARS
20
100
200
300
500
1000
HEIGHT IN FEET
100,000
80,000
60,000
40,000
20,000
0
90° 60° 40° 30° 20° 10° 0° 10° 20° 30° 40° 60° 90°
NORTH
LATITUDE
SOUTH
MINNEAPOLIS
SAN ANGELO
MARSHALL ISLANDS
CANAL ZONE
SAO PAULO
500
400
300
200
100
25
493 (1)
215 (1)
292 (2)
275 (7)
243 (5)
202 (5)
161 (6)
117 (5)
63 (6)
50 (5)
33 (4)
29 (4)
19 (3)
17 (4)
12 (3)
61 (5)
20 (4)
8 (2)
3 (6)


TOTAL TRITIUM ATOMS PER 10^{-5} GRAMS OF AIR
EXCESS CARBON-14 ATOMS PER 10^{-5} GRAMS OF AIR
0
100
200
300
ALTITUDE FEET
1955 1956 1957 1958
47-50,000
58-68,000
70-78,000
80-83,000
88-91,000

Appendix B-1

FILTERING EFFICIENCY OF IPC FILTER PAPER FOR PARTICULATE NUCLEAR DEBRIS AT LOW AIR FLOW RATE

INTRODUCTION

The primary objective of this operation was to determine the collection efficiency of IPC[1] filter paper at a linear ambient air flow rate through the paper of about 80 feet per minute[2] for the physical particles of CASTLE debris containing the strontium-90 isotope. Other objectives to be realized from this operation were the collection efficiency of this filter at this low flow rate for fresh nuclear debris and the collection efficiencies for both old and fresh nuclear debris at each of about 2,600 and 3,500 feet per minute linear ambient flow rates.

Although the prime objective was the determination of efficiency versus source of the debris, once this was established some general conclusions may be possible for the efficiency versus particle size by establishing general relative particle size from considerations such as chemical composition and history of the particles.

At the time of this operation it was expected that the stratospheric debris obtained would be composed of debris from IVY (November 1952) CASTLE (March-May 1954), a USSR event of November 1955, and REDWING (May-July 1956).

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[1] Filter paper developed by the Institute of Paper Chemistry of Appleton, Wisconsin.

[2] This is the general ambient flow rate through a balloon borne particulate filter at about 40,000 feet developed by General Mills, Inc., for the Atomic Energy Commission by which particulate samples have been obtained at from 40,000 to 100,000 feet altitude. The ambient air velocity is a direct function of the blower rpm which increases at 90,000 feet by about a factor of 1.5 over that at 40,000 feet.

EXCESS CARBON - 14 ATOMS PER 10^{-5} GRAMS OF AIR

In order to separate such a mixture of debris into those portions contributed by each source one must have either:

1. A sufficient variety of isotopes with appropriate half-lives such that one isotope will only be present from the most recent event, another isotope can only be present from the two most recent events, etc., coupled with the source time and isotopic fission yield of each event, or,

2. A sufficient number of long-lived isotopes of varied half-lives where each source contributes appreciably to the activity of each isotope so that the separation may be accomplished by a series of simultaneous mathematical equations. Source dates and individual isotopic fission yields are also essential to this solution.

Knowing the individual event dates, total fissions produced and individual isotopic fission yields for each event of a relatively closely spaced series of individual events allows the grouping of such a series into a single source for such computational purposes once nearly homogeneous mixing of debris in the atmosphere is achieved. CASTLE debris is presumed to have achieved this homogeneous condition and hence may be treated as a single source by computing a mean origin date for each isotope. At the time this sampling operation was planned, it was expected that the REDWING debris could be treated in much the same manner with reasonable success.

The time spacing between the four general sources contributing to the gross debris expected in the samples, plus the absence of a sufficient number of abundant fission isotopes of appropriate half-lives to accomplish and verify a 4-component simultaneous equation solution, indicated that approach 1 above was the most reasonable. Therefore, each sample was subjected to radiochemical analysis for a variety of abundant fission isotopes of varying half-lives in order to identify the amount each source contributed to the gross sample.

Unfortunately, the REDWING debris did not become sufficiently mixed to allow treatment as a composite mixture of all the large events.

Lacking a unique separation of the gross debris into the various source components, it is possible only to arrive at the apparent filtering efficiency for groups of particles, probably of the same relative size, for each of the three flow rates.

OPERATIONS

These operations were conducted at Minneapolis, Minnesota, during the period 7-14 August 1956. Within this period, four individual sampling operations were conducted, each on a separate day. Each sampling operation was to be conducted in the stratosphere. Inasmuch as the maximum sampling altitude was 40,000 feet by virtue of the operational altitude limit for the jet aircraft (T-33) employed, sampling was conducted only when the tropopause was below 40,000 feet.

Each individual sampling operation consisted of the balloon borne particulate filter sampling at 40,000 feet and two jet aircraft flying around the balloon borne filter at the same level. Normally the balloon borne device filtered for about 90 minutes and the two jet aircraft filtered simultaneously for about a 60 minute period within the 90 minute interval in which the balloon borne device was filtering. Each jet aircraft was equipped with two F-33 type filtering foils[3/] - one on each wing tip. All IPC filter paper used in this operation was of a common and uniform weight (15 grams/sq. ft. ± 10%). For each individual sampling operation, one aircraft carried two sheets of IPC filter paper placed front to back in one foil - essentially equivalent to a single sheet of paper of double density - and a single sheet of IPC in the other foil.

For control and identification purposes each separate daily sampling operation was identified by a four digit operational number. Each separate sample (IPC type filter paper) collected in that filtering operation was identified by a suffix to the operational number:

- - - - - - - - - - - - - - - - -

3/ A ram type air filter which filters 14.7 ambient cubic feet of air per minute of filtering per statute mile per hour velocity (true - not indicated) of the aircraft.

-HA identifies the balloon borne filter sample,

-1A identifies the first (forward) filter sample in the foil containing the two sheets of filter paper,

-1B identifies the second (rear) filter sample in the same foil,

-2 identifies the single filter sample in the second foil of the same aircraft, and

-4 identifies the single filter sample collected by the other jet aircraft.

The -HA samples represent collections at an ambient air flow rate through the filter of about 80 feet per minute while -1A samples represent collections at a flow rate of about 2,600 feet per minute. Samples -2 and -4 represent collections at ambient flow rates of about 3,500 feet per minute. The filter papers for the HA samples were 5 square feet in area each while all the other samples were obtained on a filter paper each of 1.75 square feet area. Pertinent information concerning each sampling operation is contained in Tables 1 through 4. It should be noted that the second aircraft (that aircraft exposing sample -4) of Operation No. 1853 was unable to maintain altitude with the balloon and other aircraft due to engine trouble. Therefore, for this individual operation, sample 1853-4 cannot be related to the other samples since the debris concentrations may be different at the different altitudes.

TABLE 1

OPERATION NO:	1853
DATE:	7 August 1956
TROPOPAUSE HEIGHT:	38,000 feet
TEMPERATURE AT FLIGHT LEVEL:	-57°C

	BALLOON BORNE FILTER	AIRCRAFT #1	AIRCRAFT #2
FILTERING ALTITUDE (Indicated)	39,500 ft.	40,300 ft.	38,000-39,300 ft.
FILTERING TIME	92 minutes	60 minutes	56 minutes

SAMPLE	Ambient Ft^3 Air Filtered	Ave. Linear Amb. Air Vel. thru Filter (Feet per Min.)	SCF[4/] Air* Filtered
1853-HA	38,016	83	9,617(±15%)
1853-1A[5/]	271,500	2,590	66,450 ± 10%
1853-1B[5/]	271,500	2,590	66,450 ± 10%
1853-2	362,000	3,450	88,600 ± 10%
1853-4	261,000	2,670	67,000 ± 10%

REMARKS REPORTED BY:

AIRCRAFT #1: Moderate turbulence at flight altitude, thin clouds with tops 36,000 - 37,000 ft. Contrails noted at 36,500 ft - stopped at about 39,000 ft. Balloon appears to have descended about 200 ft. during filtering interval. Aircraft #2 appears to be about 1,000 ft. lower, pulling contrails.

AIRCRAFT #2: Topped thin clouds at 37,000 ft. Light to moderate turbulence. Unable to maintain altitude due to engine trouble.

*Error limits are estimates.

4/ Standard cubic feet (SCF) of air computed at 1,013 millibars atmospheric pressure and 59° F temperature.

5/ From the known concentration of debris per SCF of air, as computed from sample 1853-2, the air flow through sample 1853-1A is computed to be 75% of the flow through 1853-2 (see Table 14). This applies for each operation.

TABLE 2

OPERATION NO:	1854
DATE:	9 August 1956
TROPOPAUSE HEIGHT:	37,400 feet
TEMPERATURE AT FLIGHT LEVEL:	-54°C

	BALLOON BORNE FILTER	AIRCRAFT #1	AIRCRAFT #2
FILTERING ALTITUDE (Indicated)	39,700 ft.	40,600 ft.	39,500-41,300 ft.
FILTERING TIME	91 minutes	60 minutes	60 minutes

SAMPLE	Ambient Ft^3 Air Filtered	Ave. Linear Amb. Air Vel. thru Filter (Feet per Min.)	SCF Air Filtered
1854-HA	37,469	82	9,.847(+15, -43)%
1854-1A	271,000	2,580	66,375 ± 10%
1854-1B	271,000	2,580	66,375 ± 10%
1854-2	361,000	3,440	88,500 ± 10%
1854-4	379,000	3,615	92,800 ± 10%

REMARKS REPORTED BY:

AIRCRAFT #1: No evidence of contrails noted from either aircraft. Some turbulence encountered at 37,500 ft. which became moderate at 40,600 ft. The balloon was observed to vary in altitude - up and down - perhaps 1,000 feet.

AIRCRAFT #2: Encountered moderate turbulence (spotty) at 39,700 ft. No contrails. Balloon was observed to vary in indicated altitude at times as much as 2,000 feet.

TABLE 3

OPERATION NO: 1855
DATE: 10 August 1956
TROPOPAUSE HEIGHT: 38,000 feet
TEMPERATURE AT FLIGHT LEVEL: -57°C

	BALLOON BORNE FILTER	AIRCRAFT #1	AIRCRAFT #2
FILTERING ALTITUDE (Indicated)	39,300 ft.	39,800-41,000 ft.	40,800 ft.
FILTERING TIME	80 minutes*	60 minutes	60 minutes

SAMPLE	Ambient Ft^3 Air Filtered	Ave. Linear Amb. Air Vel. thru Filter (Feet per Min.)	SCF Air Filtered
1855-HA	33,117	83	8,256(+20, -22)%
1855-1A	283,500	2,705	72,450 ±10%
1855-1B	283,500	2,705	72,450 ±10%
1855-2	378,000	3,605	92,600 ±10%
1855-4	360,000	3,430	88,100 ±10%

REMARKS REPORTED BY:

AIRCRAFT #1: Sky conditions quite clear. Contrails observed from 36,800 through 37,800 feet. Slight turbulence at 36,000 feet. Balloon appeared steady during observation period.

AIRCRAFT #2: Weather clear. Moderate turbulence at 32,000 feet. Contrails noted from 37,000 feet to 40,000 feet. Balloon appeared steady at float altitude.

*This time has a possible 10 per cent error due to mechanical failure.

TABLE 4

OPERATION NO:	1860
DATE:	14 August 1956
TROPOPAUSE HEIGHT:	39,500 feet
TEMPERATURE AT FLIGHT LEVEL:	-59°C

	BALLOON BORNE FILTER	AIRCRAFT #1	AIRCRAFT #2
FILTERING ALTITUDE (Indicated)	39,300 ft.	41,000-41,500 ft.	41,000 ft.
FILTERING TIME	98 minutes	60 minutes	45 minutes

SAMPLE	Ambient Ft^3 Air Filtered	Ave. Linear Amb. Air Vel. thru Filter (Feet per Min.)	SCF Air Filtered
1860-HA	39,490	81	9,836(+16, -20)%
1860-1A	279,000	2,660	65,100 ±10%
1860-1B	279,000	2,660	65,100 ±10%
1860-2	372,000	3,545	86,800 ±10%
1860-4	270,000	3,430	63,000 ±10%

REMARKS REPORTED BY:

AIRCRAFT #1: Contrails noted at 39,000 feet and again near 42,000 feet. Thin altostratus clouds at 40,000 feet. No turbulence encountered.

AIRCRAFT #2: Very thin scattered clouds. Light turbulence noted at 40,000 feet. Contrails noted near 42,000 feet. Filtered for only 45 minutes due to loss of fuel from siphoning overboard during climb-out.

DATA EVALUATION

Tables 5, 6, 7 and 8 list the measured activities in counts per minute (cpm) for each isotope isolated in the radiochemical analysis.

The strontium-90 values were obtained by milking yttrium-90 from the strontium samples. The measured activities have all been corrected to the arbitrary time of 1 August 1956 and are expressed in cpm under standard counting conditions. Those results indicated by an asterisk are the average of two determinations (of not greater than 5 per cent spread) made by rerun of the sample to check the original value. It should be noted that low counting rates for strontium-90 were obtained for all HA and 1B samples, and for zirconium-95 of sample 1860-HA, consequently, these values should be considered less accurate than the other values.

If the reader desires to express the activities (cpm), as listed in Tables 5 through 8, in disintegrations per minute (dpm), these may be obtained by dividing the listed cpm by the appropriate isotopic counting efficiency as listed in Table 9 following. Also included in Table 9 are the half-lives for the various isotopes as used in this report along with the assumed value of the isotopic fission yield for thermonuclear bombs.

By examination of the radiochemical data for each individual sampling operation, expressed in combinations of isotopic activity ratios (tabulated in Tables 10, 11 and 12), some general conclusions can be drawn. These conclusions may be summarized as follows:

1. The very excellent agreement between the individual isotopic ratios for samples 1A, 2 and 4 of each individual sampling operation indicates that:

   a. A high degree of reliability was achieved in the chemical separation and in the activity assay. This degree of reliability may, therefore, be assumed to include samples HA and 1B.

   b. There is no preferential filtering for any of the individual isotopes between samples 1A, 2 and 4 due to any differences in linear ambient air velocities through the filters within the flow rate limits for these particular samples. Particular attention is called to sample 1853-4 which was collected at a lower altitude than 1853-1A and 1853-2 and where the concentration of gross debris was of the order of only one-fourth that at the higher altitude (see Table 5). In spite of this difference in altitude and concentration, the isotopic ratios of sample 4 agree remarkably close to those for samples 1A and 2.

2. Although the flow rates through samples 1A and 1B are identical by filter placement, very large differences in isotopic ratios are observed. This must mean, beyond doubt, that filter 1A filtered the various isotopes with a different efficiency than did filter 1B, which can only be attributed to the presence of particles of different sizes with different isotopic ratios. From b above, the same isotopic filtering efficiencies - hence, filtering efficiency for different sized particles - as apply to sample 1A apply also to samples 2 and 4.

3. The large variation in isotopic activity ratios noted between sample HA and sample 1A (also samples 2 and 4) indicates very selective isotopic filtering of the balloon

TABLE 5

ISOTOPIC ACTIVITIES SAMPLES 1853

Isotope	-HA	-1A	-1B	-2	-4**
Sr^{89}	3.432×10^{3}*	8.412×10^{4}*	Lost	Lost	2.408×10^{4}*
Sr^{90}	2.627×10^{1}	5.325×10^{2}	Lost	Lost	1.602×10^{2}
Zr^{95}	1.596×10^{3}*	2.103×10^{4}*	2.621×10^{2}	2.929×10^{4}	6.828×10^{3}
Ba^{140}	6.543×10^{3}*	1.225×10^{5}	2.051×10^{3}*	1.324×10^{5}	3.165×10^{4}
Ce^{141}	4.283×10^{3}	6.645×10^{4}*	Lost	9.016×10^{4}	2.075×10^{4}
Ce^{144}	3.611×10^{2}	4.797×10^{3}*	Lost	6.809×10^{3}	1.745×10^{3}

** Collected at lower altitude than other samples.

TABLE 6

ISOTOPIC ACTIVITIES SAMPLES 1854

Isotope	-HA	-1A	-1B	-2	-4
Sr^{89}	3.208×10^{3}*	1.059×10^{5}	Lost	1.510×10^{5}*	1.383×10^{5}*
Sr^{90}	2.645×10^{1}	8.333×10^{2}	Lost	1.146×10^{3}*	1.088×10^{3}
Zr^{95}	1.509×10^{3}*	2.507×10^{4}	4.327×10^{2}	3.309×10^{4}	2.795×10^{4}*
Ba^{140}	4.922×10^{3}*	1.111×10^{5}	2.632×10^{3}*	1.426×10^{5}	1.249×10^{5}
Ce^{141}	3.871×10^{3}*	6.972×10^{4}	Lost	9.644×10^{4}	8.448×10^{4}*
Ce^{144}	3.761×10^{2}*	6.469×10^{3}	Lost	8.560×10^{3}	8.077×10^{3}*

All Isotopic Activities (cpm) Corrected to 1 August 1956.

* Value is average of two determinations; lost - isotope lost in chemical separation.

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TABLE 7

ISOTOPIC ACTIVITIES SAMPLES 1855

Isotope	-HA	-1A	-1B	-2	-4
Sr^{89}	2.141×10^{3}*	7.381×10^{4}	Lost	1.046×10^{5}*	8.139×10^{4}
Sr^{90}	2.806×10^{1}	9.139×10^{2}*	Lost	1.272×10^{3}	1.051×10^{3}
Zr^{95}	9.249×10^{2}*	1.816×10^{4}	2.944×10^{2}*	2.436×10^{4}	1.962×10^{4}
Ba^{140}	2.835×10^{3}*	7.879×10^{4}	1.591×10^{3}*	1.061×10^{5}	8.613×10^{4}
Ce^{141}	2.148×10^{3}*	4.817×10^{4}	Lost	5.713×10^{4}	4.767×10^{4}
Ce^{144}	2.335×10^{2}*	5.981×10^{3}	Lost	8.050×10^{3}	6.653×10^{3}

TABLE 8

ISOTOPIC ACTIVITIES SAMPLES 1860

Isotope	-HA	-1A	-1B	-2	-4
Sr^{89}	1.856×10^{3}*	8.624×10^{4}*	6.194×10^{3}*	1.170×10^{5}*	7.113×10^{4}*
Sr^{90}	9.787×10^{0}	3.640×10^{2}	1.822×10^{1}*	4.632×10^{2}	2.844×10^{2}
Zr^{95}	(6.481×10^{2})	1.365×10^{4}*	5.437×10^{2}*	1.878×10^{4}	1.065×10^{4}
Ba^{140}	4.019×10^{3}	1.519×10^{5}*	7.391×10^{3}*	1.916×10^{5}*	1.127×10^{5}*
Ce^{141}	2.233×10^{3}	6.459×10^{4}	2.903×10^{3}	8.499×10^{4}	Lost
Ce^{144}	1.138×10^{2}	3.061×10^{3}	1.160×10^{2}	3.767×10^{3}	Lost

All Isotopic Activities (cpm) Corrected to 1 August 1956.

* Value is average of two determinations. ( ) Value based on 3 per cent yield. Lost - isotope lost in chemical separation.

TABLE 9

ISOTOPE COUNTING EFFICIENCIES AND FISSION YIELD VALUES

Isotope	Counting Efficiency	λ (day^{-1})	Assumed Thermonuclear Fission Yield (%)
Sr^{89}	0.547	0.0137_5	2.9_3
Sr^{90}	0.393	6.78×10^{-5}	3.5
Y^{91}	0.598	0.0121	3.6_5
Zr^{95}	0.216	0.0107	5.1_7
Mo^{99}	0.521	0.2518	5.9
Ba^{140}	0.398	0.0542	4.8_8
Ce^{144}	0.155	0.0025	4.4_2
Nd^{147}	0.338	0.0626	2.8_7
Cs^{137}	0.327	7.14×10^{-5}	5.76

TABLE 10

ISOTOPE COUNT RATE RATIOS to Zr^{95}

(All isotopic count rates per minute adjusted to 1 August 1956)

Sample	Sr^{89}	Sr^{90}	Ba^{140}	Ce^{141}	Ce^{144}
		$(x10^{-2})$			
1853 - HA	2.15	1.65	4.10	2.68	0.226
1853 - 1A	4.00	2.54	5.83	3.16	0.228
1853 - 1B	-	-	7.82	-	-
1853 - 2	-	-	4.52	3.08	0.232
1853 - 4*	3.53	2.35	4.64	3.04	0.256
1854 - HA	2.13	1.75	3.26	2.56	0.249
1854 - 1A	4.23	3.33	4.04	2.78	0.258
1854 - 1B	-	-	6.08	-	-
1854 - 2	4.57	3.46	4.31	2.92	0.259
1854 - 4	4.95	3.89	4.47	3.02	0.289
1855 - HA	2.32	3.07	3.07	2.32	0.253
1855 - 1A	4.07	5.03	4.34	2.65	0.329
1855 - 1B	-	-	5.40	-	-
1855 - 2	4.29	5.22	4.36	2.35	0.331
1855 - 4	4.15	5.36	4.39	2.43	0.339
1860 - HA	2.86	1.51	6.20	3.45	0.176
1860 - 1A	6.32	2.67	11.14	4.73	0.224
1860 - 1B	11.30	3.35	13.60	5.34	0.213
1860 - 2	6.23	2.47	10.21	4.52	0.201
1860 - 4	6.68	2.67	10.58	-	-

* Because of altitude of collection this sample cannot be compared to other samples of that set.

TABLE 11

ISOTOPE COUNT RATE RATIOS to Ce^{144}

(All isotopic count rates per minute adjusted to 1 August 1956)

Sample	Sr^{89}	Sr^{90}	Ba^{140}	Ce^{141}
		$(x10^{-2})$		
1853 - HA	9.51	7.28	18.12	11.86
1853 - 1A	17.53	11.10	25.55	13.86
1853 - 1B	-	-	-	-
1853 - 2	-	-	19.45	13.24
1853 - 4*	13.80	9.18	18.14	11.89
1854 - HA	8.53	7.04	13.09	10.30
1854 - 1A	16.38	12.88	17.18	10.78
1854 - 1B	-	-	-	-
1854 - 2	17.65	13.39	16.66	11.27
1854 - 4	17.12	13.47	15.46	10.46
1855 - HA	9.18	12.02	12.14	9.20
1855 - 1A	12.34	15.27	13.17	8.05
1855 - 1B	-	-	-	-
1855 - 2	13.00	15.80	13.18	7.10
1855 - 4	12.23	15.80	12.95	7.16
1860 - HA	16.31	8.60	35.30	19.62
1860 - 1A	28.18	11.90	49.61	21.10
1860 - 1B	53.40	15.70	63.70	25.03
1860 - 2	31.08	12.30	50.90	22.57
1860 - 4	-	-	-	-

* Because of altitude of collection this sample cannot be compared to other samples of that set.

TABLE 12

VARIOUS ISOTOPE COUNT RATE RATIOS

(All isotopic count rates per minute adjusted to 1 August 1956)

Sample	Ce^{141}/Ba^{140}	Sr^{89}/Sr^{90}
1853 - HA	0.654	130.6
1853 - 1A	0.542	157.8
1853 - 1B	-	-
1853 - 2	0.681	-
1853 - 4*	0.656	150.3
1854 - HA	0.786	121.3
1854 - 1A	0.627	127.1
1854 - 1B	-	-
1854 - 2	0.676	131.8
1854 - 4	0.677	127.1
1855 - HA	0.757	76.4
1855 - 1A	0.612	80.8
1855 - 1B	-	-
1855 - 2	0.538	82.3
1855 - 4	0.554	77.4
1860 - HA	0.556	189.7
1860 - 1A	0.425	237.0
1860 - 1B	0.393	340.0
1860 - 2	0.444	252.5
1860 - 4	-	250.0

* Because of altitude of collection this sample cannot be compared to other samples of that set.

borne filter at the low air flow rates. This condition indicates the presence of a variety of particle sizes with different isotopic ratios in the gross nuclear debris. Further, as will be discussed later, the collection efficiency at low flow rates is apparently very dependent on particle size - this dependence of collection efficiency on particle size is not exhibited at flow rates comparable to that for samples 1A, 2 and 4.

4. By comparing the isotopic activity ratios for equivalent type samples between the four sampling operations, it is evident that gross debris of a different character was present on each of the separate days when sampling was conducted. This day-to-day change in character of the gross debris is probably to be attributed to the REDWING component of the gross debris. Since the extreme variations are noted primarily in the isotopes with relatively short half-lives such that they could be only from the REDWING events.

5. It is probable that the fission isotopes with short-lived gaseous or highly volatile precursors tend to condense in smaller particles than the other fission isotopes. Of the isotopes under consideration in this report, the strontium and barium isotopes have such precursors while zirconium and the ceriums do not. In the sampling with the double filters (samples 1A and 1B) it would be expected that a higher percentage of the smaller particles would pass the first filter (1A) and be collected on the second filter (1B) than would be the case for the larger particles. From Tables 10 through 12 it may be noted that the activity ratios of strontium-89 and barium-140 to zirconium-95 and cerium-144 for all 1B samples are higher than the ratios for all corresponding 1A samples. Minor differences in the activity ratios between samples 1A and 1B exist for the various combinations of the ceriums, zirconium-95, and strontium-90.

6. From Tables 10 through 12 a comparison of the isotopic activity ratios for samples HA and 1A, 2 or 4 shows that sample HA is deficient in strontium and

and barium in comparison to zirconium-95 or cerium-144. It will be noted that only slight differences are observed in the cerium-144 to zirconium-95 activity ratios. From these observations, accepting the particle size theory based on gaseous or volatile precursor offered in 5 above, it may be concluded that the filter efficiency at the low flow rate of the HA filter is very dependent upon particle size with efficiency increasing with particle size. Further, from the large differences in isotopic ratios, it may be concluded that either there is a large difference in particles sizes in the REDWING debris or else the filtering efficiency at the low air flow rate is very strongly a function of particle size.

From the isotopic ratios as tabulated in Tables 10, 11 and 12, it is evident that there is no difference in isotopic filtering efficiencies between samples 1A and 2. Therefore, it is concluded that the overall efficiency of these filters is essentially identical and that the differences in the gross activities collected (see Tables 5 through 8) are solely a function of the reduced air flow through filter 1A by virtue of the added filter 1B. Since samples 1A and 2 were obtained simultaneously by the same aircraft, a direct comparison of the activities collected is a direct measure of the relative air flow difference through these filters. Table 13 is a tabulation of the ratios of isotopic activity for sample 1A to the corresponding sample 2 expressed as a percentage. This figure averages 75 per cent with only small deviations and indicates therefore that the addition of the second filter (1B) reduces the airflow through a single filter by about 25 per cent.

From the expression $\xi \cong (1 - B/A)$, where B/A is the ratio of activities for a common isotope from samples 1B and 1A, respectively, and ξ is efficiency, the individual isotopic collection efficiencies for filter 1A may be approximated. These values are tabulated in Table 14. It is apparent from these results that the collection efficiency of the IPC filter paper at the airflow rate through filter 1A or greater (2, 600 ft/min. and up) is not an appreciable function of particle size within the size range of particles in this debris. A collection efficiency of 95 per cent for all sized nuclear debris particles adequately covers the observed data for the aircraft filters.

Since the collection efficiencies for samples 1A, 2 and 4 may all be taken as identical, the isotopic collection efficiencies for the balloon borne filter (the HA sample) may be computed by comparison

TABLE 13

AIR FLOW THROUGH DOUBLE FILTERS (1A and 1B) AS COMPARED TO SINGLE FILTER (2)

Sample	Sr^{89}	Sr^{90}	Zr^{95}	Ba^{140}	Ce^{141}	Ce^{144}
1853 (-1A/-2)x 100	-	-	71.9	92.6*	73.7	70.5
1854 (-1A/-2)x 100	70.2	72.7	75.8	77.9	72.3	75.6
1855 (1-A/-2)x 100	70.6	71.8	74.6	74.3	84.3	74.3
1860 (-1A/-2)x 100	73.7	78.6	72.7	79.3	76.0	81.3

Overall Average = 75 per cent

* Apparently a "sport" and not included in overall average.

TABLE 14

ISOTOPIC COLLECTION EFFICIENCIES (%) AT HIGH AIR FLOW RATES FROM SAMPLES - 1A and -1B

Operation	Sr^{89}	Sr^{90}	Zr^{95}	Ba^{140}	Ce^{141}	Ce^{144}
1853	-	-	98.8	98.3	-	-
1854	-	-	98.3	97.6	-	-
1855	-	-	98.4	98.0	-	-
1860	92.8	95.0	96.0	95.1	95.5	96.2

TABLE 15

PER CENT COLLECTION EFFICIENCY OF BALLOON BORNE FILTER (HA FILTER) BASED UPON SAMPLES 1A (at 75% of 2), 2 and 4

Sample	Sr^{89}	Sr^{90}	Zr^{95}	Ba^{140}	Ce^{141}	Ce^{144}
1853 - 1A	27	32	50	35	42	49
1853 - 2	-	-	48	43	42	46
1854 - 1A	19	20	38	28	36	37
1854 - 2	18	20	39	29	34	38
1854 - 4	21	22	48	35	41	42
1855 - 1A	23	25	41	29	36	31
1855 - 2	22	24	40	31	40	31
1855 - 4	27	27	48	33	46	36
1860 - 1A	14	17	31	17	21	23
1860 - 2	13	18	29	18	21	25
1860 - 4	16	21	37	22	-	-

to each of the samples 1A, 2 and 4 individually. This is accomplished by determining the gross isotopic concentration per unit mass of air from samples 1A (75% of 2), 2 and 4 and applying these concentrations to filter HA to determine its collection efficiency. Table 15 is a tabulation of the isotopic collection efficiency of the HA filter corrected for a 95 per cent collection efficiency for filters 1A, 2 and 4. It will be noted that the HA filter efficiency for the strontium isotopes is the lowest value. This is consistent with a decrease in collection efficiency for the smaller particles at this low air flow rate. The zirconium-95 and cerium isotopes, which should be associated with the larger particles, show the greatest efficiencies. The barium-140 collection efficiency appears as an intermediate value consistent with the gaseous precursor theory since the half life of Xe-140 is less than that for Kr-89 or 90. It would be expected that the cerium-144 activity present from the "old" events would be obscured by the cerium-144 activity from the REDWING debris by virtue of the high concentration of REDWING debris intercepted and decay factors.

SUMMARY

In summary it may be concluded that the collection efficiency of the IPC filter paper for air flow rates of about 2,600 ambient feet per minute or greater is about 95 per cent and independent of particle size. For ambient air flow rates about 80 feet per minute the collection efficiency is strongly dependent on particle size and has an efficiency of about 20 per cent for the smaller particles of fresh nuclear debris - this size may be comparable to the "old" debris residing in the atmosphere for at least 2 to 4 years. For the larger particles in fresh nuclear debris still airborne after several weeks the collection efficiency is of the order of 30 to 50 per cent. It should be noted that an apparent collection efficiency of 30 to 50 per cent would be obtained from approximately a 2 to 1 ratio of particles filtered with efficiencies of about 20 per cent and greater than 90 per cent, respectively. It would be expected that particles of a few microns in diameter would be filtered with greater than 90 per cent efficiency even at the low air flow rate of only about 80 feet per minute. It is impossible to state whether or not the REDWING debris particles in these samples were of such a size and distribution so as to yield this observed result.

Representative HOLIFIELD. At this point I would like to insert a statement by Dr. S. C. Stern, of General Mills:
(The statement referred to follows:)

THE COLLECTION EFFICIENCY OF I.P.C.
FILTER MATS FOR RADIOACTIVE PARTICULATES
IN THE STRATOSPHERE

Submitted by: S. C. Stern, Principal Scientist, Mechanical Division of

GENERAL MILLS, INC.

Summary

Under contract with the Division of Biology and Medicine of the U.S.A.E.C., the Research Department of the Mechanical Division of General Mills, Inc. has been conducting a laboratory and field test evaluation of the collection efficiency of I.P.C. filter mats for radioactive particulates resident in the stratosphere. From preliminary test results, it is evident that the levels of activity, credited to I.P.C. filter mats obtained from "Ash Can" sampling devices, should be increased at least by a factor of 1.7. There is some other evidence that, under unusual circumstances such as a very stable atmosphere, recycling of sampled air may occur and that this factor of 1.7 may be increased to as high as 25.

From the test data obtained at altitude, the estimated size of the radioactive debris is about 0.15 microns for material having a density of 2.5.

Statement

Between April and May of 1956, the Mechanical Division of General Mills, Inc. initiated an investigation of stratospheric radioactivity by launching and recovering nine balloons carrying aerosol sampling devices into the stratosphere. These experimental flights were performed tc demonstrate to the U.S.A.E.C. that airborne radioactive debris resident in the stratosphere could be sampled in sufficient quantity for accurate radiochemical assays. The major components of the aerosol sampling device consisted of a fibrous filter mat, fabricated by the Institute of Paper Chemistry, Appleton, Wis., and a large-volume (500 ft^3/min) air mover. These components were housed in a cylindrical container which had a hinged cover; with usage this aerosol sampling unit became known as "Ash Can".

Although the U.S.A.E.C. was cognizant of the fact that the particulate retention of the fibrous filter mat had not been determined as a function of particle size and air velocity through the filter at stratospheric air pressures, an urgent requirement existed to obtain an estimate of the levels of radioactivity in the stratosphere. A network of four stations was then established to periodically launch and recover balloon-borne stratospheric particulate sampling "Ash Cans".

It should be stated at this time that responsible scientific members on the staff of the U.S.A.E.C. were aware that the level of radioactivity credited to "Ash Can" filter mats would require subsequent revision after the particulate retention of the mat had been thoroughly studied in the laboratory and verified by field test.

In January of 1957, the Division of Biology and Medicine of the U.S.A.E.C. awarded a contract to the Research Department of the Mechanical Division of General Mills, Inc. which has these objectives:

1. To determine the particulate retention of the Institute of Paper Chemistry (I.P.C.) filter mat as a function of air velocity through the filter mat, particle size and simulated air densities existing in the stratosphere.

2. To determine the optimum operating conditions for maximum retention of particulates with minimum pressure drop through the fibrous mat.

3. To design, develop and fabricate an optimized particulate air sampling device which could be used as a standard and flown simultaneously with "Ash Can".

4. To conduct a series of experimental balloon flights into the stratosphere for the purpose of:

(a) determining the internal accuracy of the levels of radiation obtained from assaying "Ash Can" filter mats.

(b) comparing the levels of radioactivity obtained with "Ash Can" filters with levels of activity obtained with the optimized collection unit on the basis of activity per standard cubic foot of air.

(c) determining by means of suitable experimental design the effective particle size of the radioactive debris resident in the stratosphere.

All the objectives cited in 1, 2 and 3 above have been satisfactorily attained and reported to the Division of Biology and Medicine of the U.S.A.E.C. The retention of the I.P.C. filter mat as a function of particle size, air

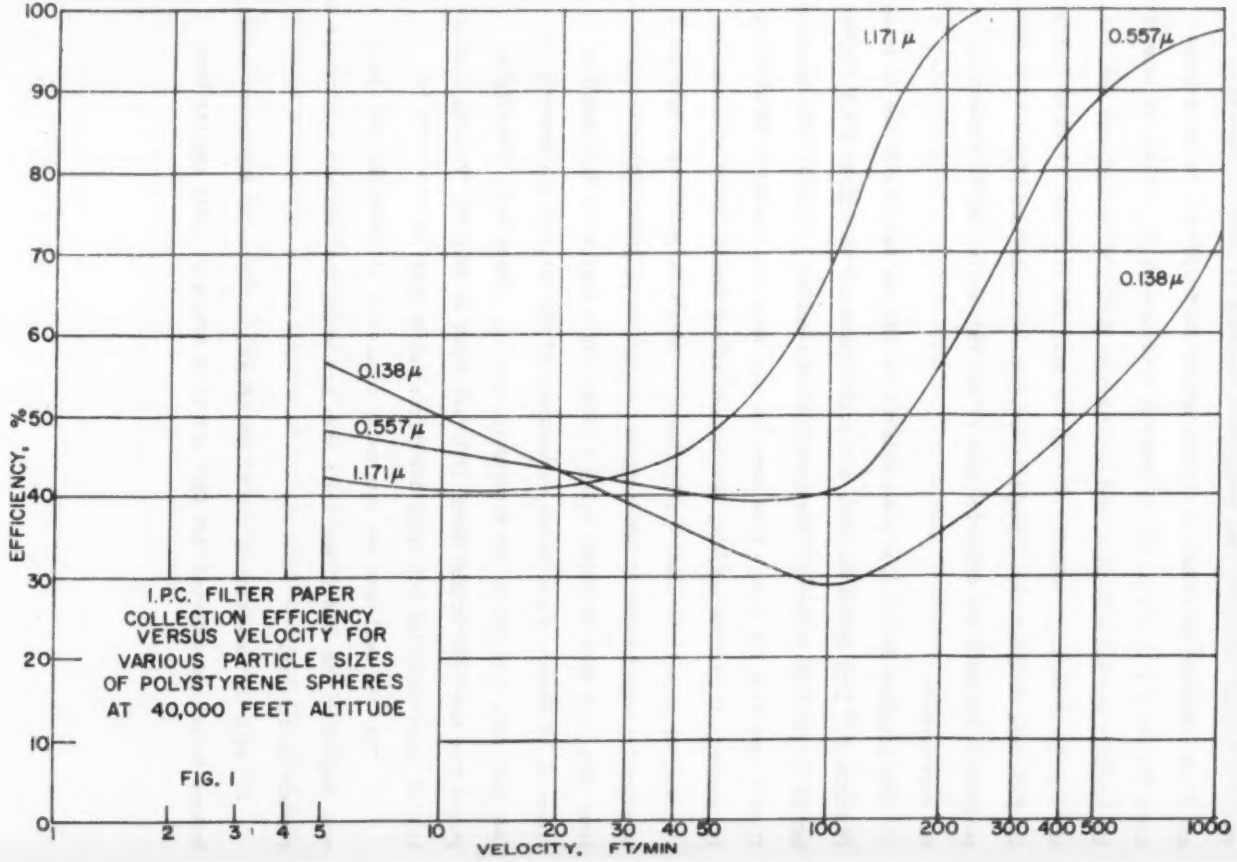
velocity through the filter and atmospheric pressure is shown in Figures 1, 2 and 3 for simulated altitudes of 40,000, 60,000 and 83,000 ft. A calibration curve for the I.P.C. filter mat in terms of a parameter, η_α, which is related to the total filter mat efficiency and a parameter, $\psi^{1/2}$, which includes particle size, particle density, velocity through the mat, and altitude, is shown in Figure 4. From data obtained from a properly designed experiment and Figure 4, it is possible to estimate the effective size of the radioactive debris present in the stratosphere.

The advanced direct-flow stratospheric particulate sampling device is shown in Figure 5. This device has been designed to pass air through an I.P.C. filter mat at a very high velocity. The levels of radioactivity obtained from assaying filters used with the direct-flow sampling unit were anticipated to be within a few percent of the true activity due to radioactive debris in the stratosphere.

All the objectives under 4 above have not been attained to this date since an extensive experimental flight program is still in progress. However sufficient data have been obtained, using a flight train similar to that shown in Figure 6, to warrant a preliminary assessment of the validity and accuracy of "Ash Can" data credited to the Minneapolis station. These data, covering a period from May 1958 through March 1959, are shown in Table I. From an examination of these data, the following deductions can be made:

1. The "Ash Can" data are internally consistent in the sense that duplicate samples on the same flight train have just about the same activity levels and standard deviations.

2. With the exception of one flight (#2366) little or no difference exists between ducted and unducted "Ash Can" levels of activity. This implies that,



I.P.C. FILTER PAPER COLLECTION EFFICIENCY VERSUS VELOCITY FOR VARIOUS PARTICLE SIZES OF POLYSTYRENE SPHERES AT 40,000 FEET ALTITUDE

FIG. 1

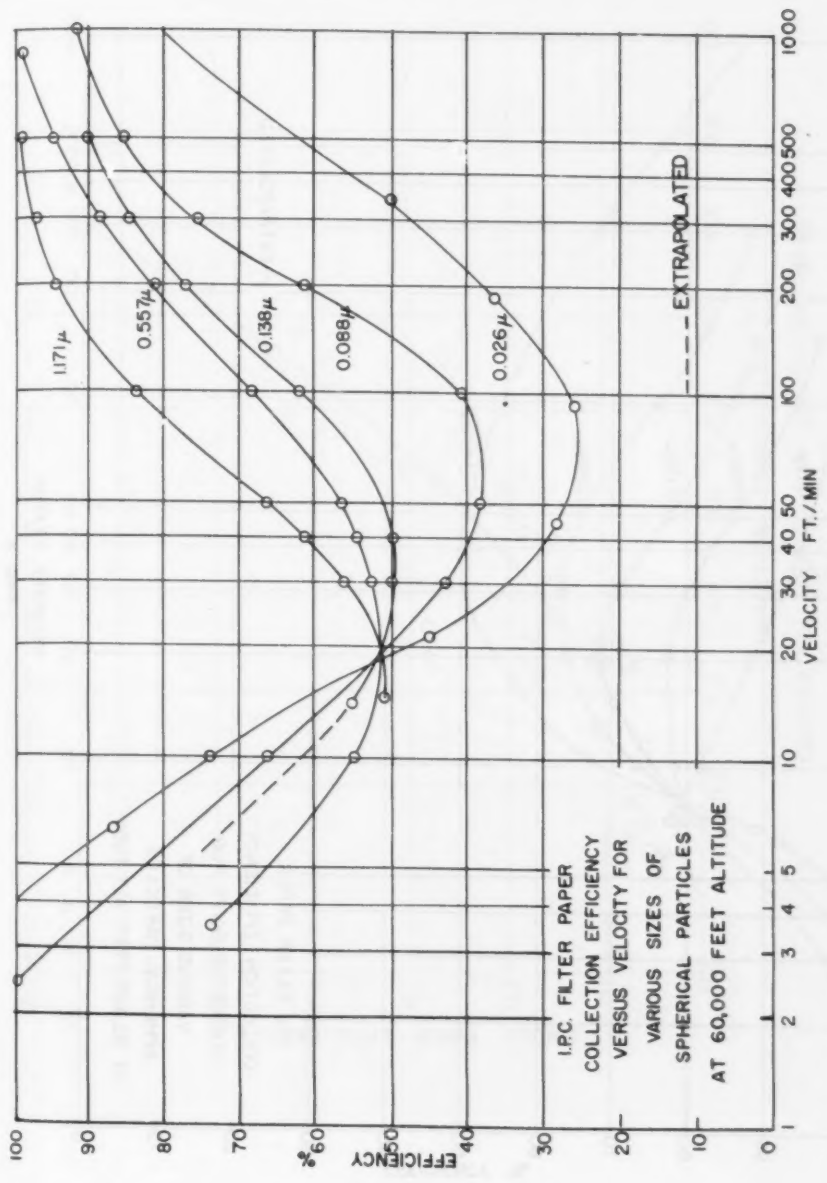

I.P.C. FILTER PAPER
COLLECTION EFFICIENCY
VERSUS VELOCITY FOR
VARIOUS SIZES OF
SPHERICAL PARTICLES
AT 60,000 FEET ALTITUDE
1.171μ
0.557μ
0.138μ
0.088μ
0.026μ
EXTRAPOLATED
EFFICIENCY %
VELOCITY FT./MIN

FIG. 2

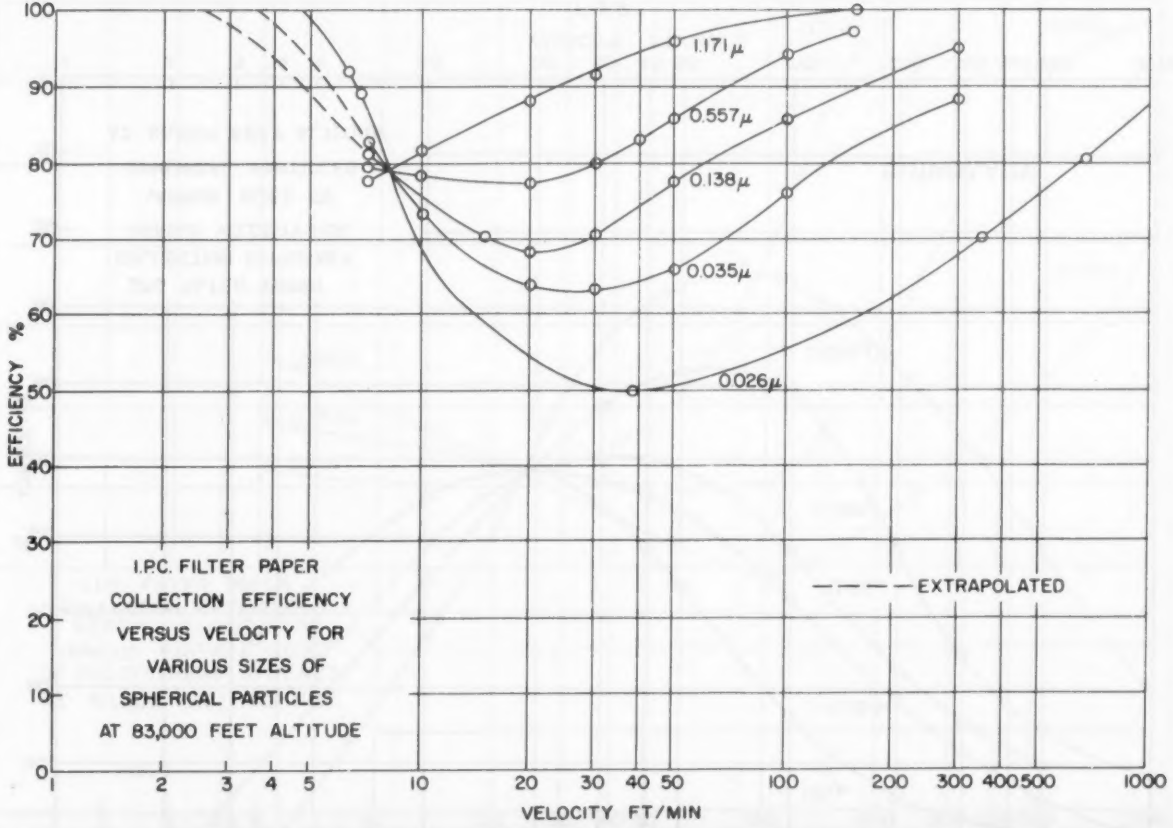
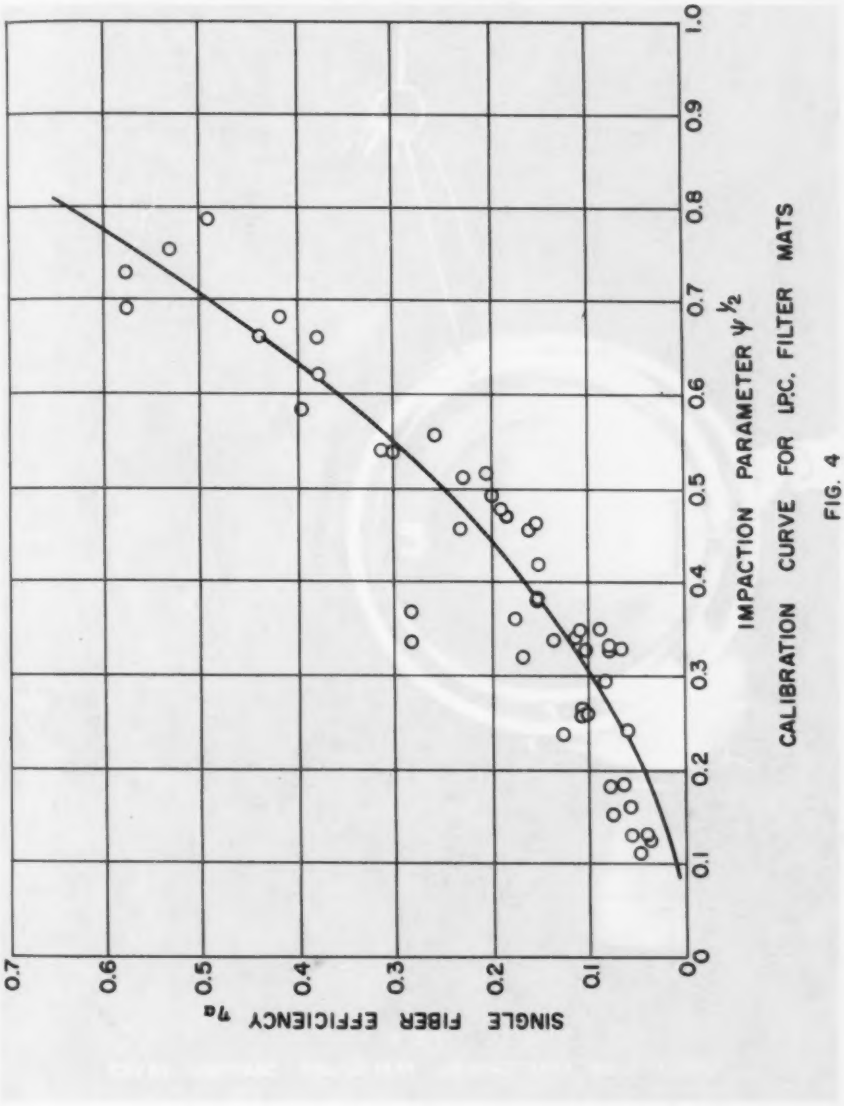

EFFICIENCY %
100
90
80
70
60
50
40
30
20
10
0
1.171μ
0.557μ
0.138μ
0.035μ
0.026μ
I.P.C. FILTER PAPER
COLLECTION EFFICIENCY
VERSUS VELOCITY FOR
VARIOUS SIZES OF
SPHERICAL PARTICLES
AT 83,000 FEET ALTITUDE
EXTRAPOLATED
1
2
3
4
5
10
20
30
40
50
100
200
300
400
500
1000
VELOCITY FT/MIN

FIG. 3

0.7



CALIBRATION CURVE FOR I.P.C. FILTER MATS

FIG. 4

VELOCITY FT/MIN

FIG. 3

FIG. 5
DIRECT - FLOW STRATOSPHERIC PARTICULATE SAMPLING DEVICE

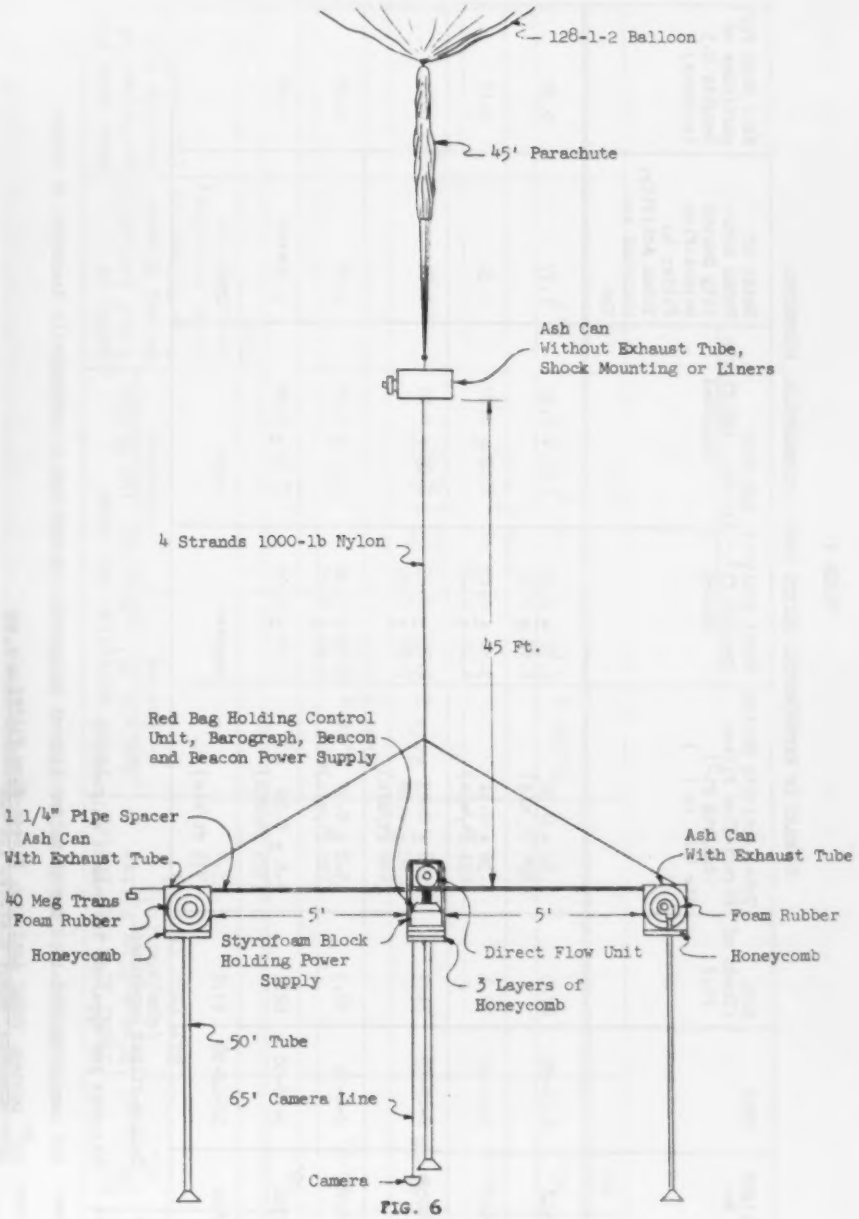


FIG. 6

QUADRUPLE PARTICLE SAMPLING FLIGHT TRAIN

TABLE I

SUMMARY OF EXPERIMENTAL FLIGHT DATA - MINNEAPOLIS, MINNESOTA

Flight No.	Date	Alt. (Thsds of ft.)	Total Activity Ducted Direct-Flow Filter (dpm/std ft^3) Air Vel. in ( )	Total Activity Ash Cans dpm/std ft^3 - Air Vel. 100 ft/min		Ratio of Total Activity Ducted Direct-Flow Filter to Total Activity, Unducted Ash Can	Est. size for particles of density 2.5 (microns)
				Ducted	Unducted		
2412	3-19-59	87.0	1.82 ± 0.38 (598 ft/min)	1.70 ± 0.35 1.68 ± 0.31	1.03 ± 0.32	1.77	0.30
2407	3-11-59	72.1	5.36 ± 0.31 (633 ft/min)	3.50 ± 0.23 4.12 ± 0.24	4.10 ± 0.27	1.31	0.15
2405*	2-19-59	71.7	2.98 ± 0.43 0.00 ± 0.28 (440 ft/min)	2.25 ± 0.23 2.23 ± 0.22	1.62 ± 0.27	1.84	0.11
2402	2-6-59	58.5	15.2 ± 0.37 (720 ft/min)**	6.03 ± 0.30 9.69 ± 0.35	9.14 ± 0.37	1.67	0.10
2362	5-28-58	62.1	4.6 ± 0.00 (735 ft/min)	1.94 ± 0.00	2.58 ± 0.00	1.78****	0.08
2400	12-12-58	57.0	25.2 (775 ft/min)	None***	0.98	25.7	

* Double-filter experiment

** Adjusted for apparent instrument malfunction

*** One sample not obtained due to malfunction of equipment. Second sample accidentally destroyed at NYOAEC

**** $\frac{Sr^{90} \text{ Ducted, Total Activity, Direct-Flow Filter}}{Sr^{90} \text{ Unducted, Total Activity Ash Can}} = 1.72$

TABLE I (Cont'd)

$\frac{Sr^{90} \text{ Ducted, Total Activity, Direct-Flow Filter}}{Sr^{90} \text{ Unducted, Total Activity Ash Can}} = 1.72$

TABLE I (Cont'd)

SUMMARY OF EXPERIMENTAL FLIGHT DATA - MINNEAPOLIS, MINNESOTA

Flight No.	Date	Alt. (Thsds of ft.)	Total Activity Ducted Direct-Flow Filter ($dpm/std\ ft^3$) Air Vel. in ( )	Total Activity Ash Cans $dpm/std\ ft^3$ - Air Vel. 100 ft/min		Ratio of Total Activity Ducted Direct-Flow Filter to Total Activity, Unducted Ash Can	Est. size for particles of density 2.5 (microns)
				Ducted	Unducted		
2401	1-9-59	58.0			2.15		
2389	10-16-58	60-61		3.76 ± 0.22 3.56 ± 0.24			
2373	6-27-58	53-66		2.71 ± 0.25	2.26 ± 0.26 2.83 ± 0.30		
2372	6-27-58	62.0			4.41 ± 0.25 4.54 ± 0.26		
2366	6-12-58	90.0		0.094 ± 0.004	0.011 ± 0.002	8.5	
2352	5-16-58	64.5			2.26		

in the main, the balloon vehicle carrying the particle collection device is subject to some vertical motion at sampling altitudes or that some relative motion exists between the balloon and the free stream velocity. This concept precludes the recycling of sampled air.

3. On the other hand, two flights (#2400 and #2366) show a large variation between the levels of activity obtained from ducted direct-flow, ducted "Ash Can" samples and unducted "Ash Cans". This variance could be attributed to instrumental malfunctioning, recycling of sampled air, or an unusual background radiation of the I.P.C. filter mat. Since no malfunction of equipment was discerned, and the background radiation of the I.P.C. filter mat is held to close tolerances, the possibility exists that recycling of the sampled air is responsible for the observed large differences in activity. This implies that there are certain cases in which the balloon vehicle carrying the particle collection device is not subject to some vertical motion at sampling altitude or that no relative motion exists between the balloon and the free stream velocity.

4. With the exception of one experimental flight (#2400) the ratio of direct-flow total radioactivity in dpm/std ft^3 to "Ash Can" total radioactivity in dpm/std ft^3 is reasonably constant, with an average value equal to 1.7. For Flight #2362, the ratio $\frac{Sr^{90} \text{ activity, Direct Flow Filter}}{Sr^{90} \text{ activity, Unducted Ash Can}}$ was found to be 1.72.

5. By means of a double-filter experiment (Flight 2405) it has been shown that when the air velocity through the filter mat is 440 ft/min, the collection efficiency of the I.P.C. filter mat is 100% for the radioactive particulates resident in the stratosphere at 71,700 ft altitude.

6. By assuming that the direct-flow filter mat has a collection efficiency of 100%, at air flow rates equal to or greater than 440 ft/min, then with but one exception (Flight #2400) the equivalent size of the radioactive debris is 0.15 microns assuming that the density of the particles is 2.5.

In conclusion it can be stated, on the basis of preliminary field test results, that existing activity levels credited to "Ash Can" samples should be increased by a factor of 1.7. There are apparently other circumstances which may increase activity levels credited to "Ash Can" by a factor as high as 25. These circumstances are under study.

With regard to the particle size of the radioactive debris in the stratosphere, it has been estimated that the equivalent particle size, for a material having a density of 2.5, is approximately 0.15 microns in diameter.

STERN, SIDNEY C. - BIOGRAPHICAL RESUMÉ

B.S. in Chemical Engineering, College of the City of New York
Graduate Study: School of Technology, CCNY
AAFTTC - Chanute AFB, Illinois
University of Maryland, CSCS, Fort Detrick, Md.

AREAS OF PROFICIENCY

Engineering: development of electrostatic, impaction and fibrous filter sampling techniques and equipment for sampling aerosols in the stratosphere. Micrometeorology: small and large scale travel and diffusion of aerosols and the determination of munition expenditure requirements. Aerosol Technology: chemical and physical properties of dynamic and static aerosols. Physics: measurement of infrared and ultraviolet radiation and their application and use in physical and biophysical problems. Physical Chemistry: mechanisms involved in the filtration of aerosols by fibrous filter beds, the detection of toxicological clouds based on physical and chemical properties.

GENERAL MILLS POSITION

Principal Scientist

EXPERIENCE

1956 - present	General Mills, Inc. Project Manager, upper atmosphere monitoring program. Supervisor of systems analysis study for an airborne munitions system.
1949 - 1956	Biolcgical Laboratories, Chemical Corps, Fort Detrick, Frederick, Maryland. Supervisor of program of aerosol detection based on chemical and physical properties of aerosol particulates.
1952 - 1956	Supervisory General Engineer, Physical Detection Branch, Physical Defense Division.
1949 - 1952	Acting Branch Chief and Principal Micrometeorologist, Meteorology Branch, F. T. and M. Division.
1946 - 1949	U. S. Air Force. Civilian meteorologist.
1941 - 1946	U. S. Air Force. Instructor in meteorology and atmospheric physics.
1937 - 1941	Textile Converting and Processing. N. J. Stern Co., New York City.

PUBLICATIONS OF SIDNEY C. STERN

--- and F. Schwartzmann. An infrared detector for measurement of the back radiation from the sky. J. Meteorol. 11: 121-29 (1954).

--- and C. W. Hill. Simple ultraviolet radiometer. Rev. Sci. Instr. 26: 1122-24 (1955).

---, D. R. Steele and O. E. A. Bolduan. A large-volume electrostatic precipitator. A. M. A. Arch. Ind. Health 18: 30-33 (1958).

---, J. Baumstark, R. Olson, and A. Schekman. A simple technique for the generation of homogeneous millimicron aerosols. To be published in June 1959 issue J. Appl. Phys.

---, W. Zeller and A. Schekman. The aerosol filter efficiency and pressure drop of a fibrous filter mat at reduced pressure. To be submitted to J. Appl. Phys. for publication.

--- and L. C. Clarke. Long wave radiometer. U. S. Patent 2,768,527 (Oct. 30, 1956).

APPENDIX C

Project Ash Can Particulate Radioactivity Data

List of Stations:

Minneapolis, Minn. (General Mills, Inc.)

Goodfellow Air Force Base, San Angelo, Texas (shown as Texas)*

France Air Force Base, Canal Zone (shown as "Canal Zone" or "Panama")*

Sao Paulo, Brazil (shown as "Southern Hemisphere", "South America" or "Brazil")*

Sioux City, Iowa (Shown as "Sioux City" or "Iowa City")*

*Detachments of 1110th Balloon Activities Group, USAF.

Notes:

"S.C.F." - Standard cubic feet (volume reduced to 1013.25 mb and 15°C)

"d/m" - disintegrations per minute

"c-date" - counting date

"B" - tungsten-185

Figure following "±" - standard counting error.

No correction has been applied for collection efficiency.

Isotope data are corrected to date of sampling.

Altitudes are in thousands of feet.

November 1956

	Rabbit	Flight	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (S.C.F.)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	Ba^{140} C-date	Ba^{140} d/m/sample	Ce^{95}	Ce^{144}	Ce^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Ce^{137}/Sr^{90}
													d/m/1000 S.C.F.						
Minneapolis	4666	1992	11-6-56	65	67	8	3716	3-11-57	15,380 ± 960	4.12 ± 0.26	6-20-57	20.8 20.9	607	680	421	638	68.2	10.2	6.77
	4708	1995	11-9-56	90	95.3	8	1080	1-29-57	9,660 ± 1,795	9.49 ± 1.76	1-25-57	32.8 ± 2.2	—	821 ± 5.7	52.4 ± 6.57	1287	31.3 ± 4.12	41.4	1.68
	4668	2001	11-17-56	50	47/44.5	32.5[1]	6572	3-7-57	13,500 ± 990	1.57 ± 0.12	6-12-57	20.8 20.9	361	315	38.5	165	22.3	7.4	4.25
Texas	4680	T-147	11-30-56	50	49.2	53.5[2]	7053	3-11-57	9,790 ± 1,080	1.35 ± 0.15	6-20-57	21.9 20.8	136	169	86.2	268	12.4	21.6	2.11
	4681	T-148	11-30-56	90	99	8	854	1-29-57	1,186 ± 578	1.48 ± 0.68	1-25-57	19.9 ± 1.6	--	254 ± 10	98.8 ± 7.79	491	28.9 ± 4.55	16.9	3.21
Southern Hemisphere	4902	S-128	11-25-56	90	90.5	8	480	1-29-57	746 ± 615	1.55 ± 1.28	1-25-57	12.6 ± 1.6	—	538 ± 14	161 ± 15	589	41.9 ± 9	4.38	9.18
	4905	S-130	11-26-56	65	65.7	8	3330	1-29-57	6,135 ± 1,898	1.84 ± 0.39	1-25-57	15.3 ± 2.4	—	363 ± 1.9	157 ± 4.1	661	38.9 ± 1.77	16	4.0

1. Stratospheric Sample.
2. Tropospheric Sample.

December 1956

	RASL[1]	Flight[2]	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (S.C.F.)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	Ba^{140} C-date	Ba^{140} d/m/sample	d/m/1000 S.C.F. Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Minneapolis	4901	2011	12-8-56	50	51	50.0[1]	7854	3-11-57	22,600 ± 1,330	2.86 ± 0.17	6-20-57	$\frac{51.2}{51.1}$	512	505	137	485	30.3	16.0	4.52
	4997	2031	12-19-56	65	66/66.5	"	6665	3-7-57	15,800 ± 1,040	2.38 ± 0.16	—	—	306	530	108.9	384	35.6	10.8	3.06
Texas	4991	T-154	12-14-56	80	83.2/86.8	"	2089	1-19-57	2,353 ± 507	1.26 ± 0.25	1-25-57	21.0 ± 1.6	—	137 ± 4.1	75.4 ± 4.1	186	33.4 ± 2.21	5.58	2.29
	4992	T-156	12-16-56	65	68/66.9	"	5616	3-11-57	16,160 ± 900	5.02 ± 0.25	6-20-57 6-21-57	$\frac{52.0}{51.6}$	475	682	213	804	58	15.5	4.67
	5025	T-159	12-21-56	50	49.5/48	44.3[1]	7928	3-8-57	2,300 ± 730	0.29 ± 0.09	—	—	45.6	60.1	10.83	85	1.64	50.6	6.60
Panama	5000	P-132	12-1-56	65	70	"	5069	3-11-57	29,000 ±12,700	9.46 ± 4.14	5-28-57	$\frac{51.3}{51.2}$	854	204.3	24.2	3446	189	19.3	1.28
Southern Hemisphere	5022	S-138	12-21-56	80	87/70.5	"	1486	3-11-57	2,480 ± 820	1.7 ± 0.58	5-28-57	$\frac{50.7}{51.2}$	94.3	477	106	572	39.3	21.85	2.7
	5041	S-144	12-28-56	90	89.9	"	969	1-19-57	648 ± 514	0.67 ± 0.53	1-25-57	17.0 ± 1.5	—	125 ± 7.2	56.9 ± 8.3	82.3	6.91 ± 4.25	11.9	8.2
	5042	S-145	12-29-56	50	47.5	51.7[2]	8399	3-11-57	1,410 ± 650	0.17 ± 0.08	5-28-57	$\frac{50.8}{51.4}$	3.08	15.3	11.89	511	0.77	14.3	15.6
	5043	S-146	12-30-56	80	80.5	"	1701	1-19-57	5,572 ± 1,688	3.28 ± 0.99	1-29-57	239 ± 5	—	115 ± 5.0	121 ± 5.8	—	—	—	—

1. Stratospheric Sample.
2. Tropospheric Sample.

January 1957

	Sample	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (S.C.F.)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	Ba^{140} C-date	Ba^{140} d/m/sample	d/m/1000 S.C.F. Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
	Minneapolis	5134	2051	1-16-57	50	46/43	32[1]	11958	3-22-57	31,790 ± 990	2.66 ± 0.08	6-20-57 6-24-57	$\frac{1.4}{5.2}$	389	561	37	284	24.8	9.83	1.49
	Texas	5172	T-165	1-17-57	90	105/106.5	8	850	3-22-57	650	0.76	6-20-57 6-24-57	$\frac{1.4}{1.4}$	106	58.6	11.93	393	7.65	51	1.56
		5173	T-167	1-18-57	65	65	36.8[1]	3857	3-22-57	34,150 ± 1,100	8.85 ± 0.36	--	--	865	3780	354	--	--	--	--
	Panama	5252	P-145	1-21-57	65	65	53.1[1]	3569	3-25-57	2,950 ± 850	0.83 ±	7-10-57	$\frac{1.9}{1.8}$	93.1	116.7	6.99	--	--	--	--
	Southern Hemisphere	5279	B-152	1-31-57	65	65	53.1[1]	3343	3-22-57	613 ± 790	0.18 ± 0.24	7-1-57	$\frac{1.7}{0.9}$	39	190	18.2	55.6	25.9	2.14	1.74

1. Stratospheric Sample.

February 1957

	HASL#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (S.C.F.)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	Ba^{140} C-date	Ba^{140} d/m/sample	d/m/1000 S.C.F. Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Minneapolis	5300	2114	2-13-57	80	79.7/76.0	S	3629	3-22-57	12,300 ± 550	3.39 ± 0.15	7-3-57	30.8 30.9	34.1	23.7	7.52	61.5	0.83	74.1	9.06
	5321	2130	2-27-57	50	42.5/39	35.3[1]	17499	3-25-57	21,000 ± 1,120	1.20 ± 0.06	--	--	104	222	21.7	75.6	11.7	6.46	1.85
	5322	2126	2-19-57	65	66.9/65.1	S	5444	3-25-57	2,830 ± 850	0.52 ± 0.16	--	--	64.5	139.7	30.0	108	7.26	14.9	4.13
Texas	5293	T-172	2-9-57	90	97.25/98.75	S	772	3-22-57	1520	0.67	7-3-57	31.9 31.0	120	342	40.4	3276	26.0	110.6	1.55
	5297	T-174	2-11-57	65	65.5	S	3229	3-22-57	18,275 ± 1,150	5.66 ± 0.37	7-1-57	31.5 31.4	345	1536	77.4	814	136	6.20	0.57
	5319	T-178	2-27-57	50	49.0/49.6	36.0[1]	7320	3-25-57	7,400 ± 970	1.01 ± 0.13	7-22-57	31.1 30.7	61.3	170	18.3	60.8	9.9	6.14	1.85
	5340	T-176	2-25-57	80	85/85.25	S	1776	3-25-57	2,230 ± 750	1.26 ± 0.42	7-22-57	30.7 31.3	60	572	147.6	160	39.7	4.03	3.72
Panama	5280	P-148	2-1-57	90	99/104	S	710	3-22-57	960	0.8	--	--	1256	3979	285	--	103000[3]	--	--
	5307	P-158	2-15-57	65	67.2/59.2	53.1[1]	4373	3-22-57	9,470 ± 800	2.16 ± 0.18	7-10-57	31.1 31.0	132	525	36.2	230	38	6.05	0.95
	5435	P-154	2-28-57	80	78	S	2180	3-25-57	8,080 ± 880	3.71 ± 0.40	--	--	227	1042	155.2	3565[3]	35	--	4.43
Southern Hemisphere	5393	S-158	2-21-57	90	89.5	S	843	3-25-57	3440	4.0.76	--	--	59.8	91.2	65.8	135	9.49	14.22	6.72
	5324	S-159	2-22-57	65	66	S	2830	3-25-57	1,780 ± 700	0.63 ± 0.25	7-22-57	31.1 30.7	407.0	227	129	109	29.8	3.66	4.33
	5395	S-160	2-23-57	80	92/71.6	S	1421	3-22-57	19,900 ± 590	14.0 ± 0.42	7-31-57	31.3 31.1	<7.0	197	113.1	4335	31	140.8	3.65

1. Stratospheric Sample.
3. Sample contaminated with cerium and strontium.

March 1957

	RASH#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (S.C.F.)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	d/m/1000 S.C.F. I^{131}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Minneapolis	5468	2151	3-13-57	65	65.7/55	32[1]	8024	4-5-57	12,250 ± 990	2.27 ± 0.12	185	849	137.1	205	69.8	2.91	1.96
	5469	2173	3-19-57	50	49.5/47	31.5[1]	8900	4-5-57	12,050 ± 1,010	1.35 ± 0.11	89.9	264	41.2	99.7	20.4	4.89	2.02
	5470	2182	3-21-57	80	81.5/55	s	4718	4-5-57	11,840 ± 1,470	2.51 ± 0.31	128	618	67.9	362	44.2	8.19	1.54
	5533	2185	3-27-57	90	67.4/58.5	s	2395	5-7-57	3,060 ± 730	1.28 ± 0.30	90.6	312	64.7	≤131	25	≤5.24	2.59
Texas	5460	T-183	3-11-57	80	77.5/78.5	s	2007	3-25-57	922 ± 890	0.46 ± 0.44	116	361	117.3	≤146	28.4	≤5.14	4.13
	5461	T-185	3-12-57	90	94/95	s	1079	4-5-57	860 ± 805	0.8 ± 0.74	179	97.8	66.5	(-859)	6.58	—	10.1
Panama	5457	P-160	3-6-57	80	80.1/81.4	s	1898	3-25-57	2,970 ± 850	1.62 ± 0.46	199	804	107.5	104	46.5	2.24	2.31
	5467	P-162	3-8-57	90	89.2/9640	s	940	4-5-57	≤890	≤0.88	≤188	38.8	47.3	≤502	≤2.93	171	≤16.1
	5468	P-163	3-9-57	65	64.5/65.1	57.3[1]	3109	4-5-57	6,980 ± 960	2.24 ± 0.31	191	625	77.5	261	47.4	5.93	1.64
Southern Hemisphere	5462	B-162	3-8-57	90	90	s	969	4-5-57	≤560	≤0.58	273	99.0	108.7	≤154	18.3	≤10.0	5.94
	5524	B-166	3-23-57	80	81.5	s	644	5-7-57	≤750	≤1.16	≤234	21.3	129.0	≤228	20.5	≤11.1	6.29
	5526	B-167	3-25-57	65	66	s	2473	5-7-57	4,780 ± 750	1.93 ± 0.30	≤72.6	267	114.8	≤191	41.0	≤4.66	2.80
	5528	B-171	3-27-57	80	80.8	s	1769	6-26-57	1,680 ± 500	0.95 ± 0.28	172	191	132.2	≤256	32.5	≤7.88	4.07

1. Stratospheric Sample.

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April 1957

	HASL#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (S.C.F.)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	d/m/1000 S.C.F. Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Minneapolis	5563	2190	4-8-57	65	65/37	31.1[1]	11211	5-7-57	19,890 ± 1,240	1.4 ± 0.09	54.0	331	14.3	≤53.5	24.8	≤2.16	1.79
	5593	2201	4-15-57	50	47.5	39.5[1]	6180	5-7-57	35,790 ± 1,140	5.79 ± 0.23	183	403	86.8	510	33.5	15.2	2.41
	5594	2203	4-17-57	80	81.5/74.35	S	3731	5-7-57	34,640 ± 1,240	9.34 ± 0.33	372	608	66.8	351	37.5	9.36	1.78
	5560	2217	4-26-57	90	80.4/93.5	S	2347	5-18-57	1,860 ± 590	0.79 ± 0.25	≤53.3	38.8	2.65	(<786)	≤1.56	--	≥1.7
	5685	2218	4-29-57	65	67.6/68	S	3120	6-17-57	17,820 ± 989	5.71 ± 0.32	263	1474	346	(<820)	138	≤5.94	2.51
Texas	5636	T-193	4-17-57	90	89.5	S	2689	5-7-57	1,600 ± 650	0.6 ± 0.24	≤58.6	11.47	7.53	≤56.4	≤1.12	50.3	≥5.72
Panama	5591	P-165	4-8-57	80	76.9/78.4	S	2091	5-18-57	≤580	≤0.28	111	229	9.52	(≤246)	<1.59	--	≤5.99
	5592	P-167	4-12-57	65	61.75/61	56.3[1]	4082	5-7-57	4,300 ± 770	1.05 ± 0.19	75	329	1.72	≤137	27.4	≤5.0	0.06
Southern Hemisphere	5637	S-173	4-9-57	90	90.4	S	894	5-7-57	940 ± 650	1.05 ± 0.73	≤215	102	24.5	(<886)	14.6	≤60.7	1.68
	5638	S-176	4-12-57	80	78.6/-90	S	1253	5-7-57	1,390 ± 670	1.11 ± 0.53	≤89	77.2	62.2	(<618)	14.4	--	4.32
	5695	S-178	4-23-57	80	68.5/90	S	1179	5-18-57	1,900 ± 590	1.61 ± 0.50	132	501	52.1	≤569	58.1	≤9.79	0.9
	5696	S-179	4-23-57	65	64	48.0[1]	3340	5-18-57	3,200 ± 640	0.96 ± 0.19	46.8	250	116.7	≤207	44.5	≤4.65	2.62
	5697	S-131	4-25-57	80	78/80.5	S	1561	5-18-57	2,470 ± 370	1.58 ± 0.24	≤103	417	134.9	≤134	42.6	≤3.14	3.17

1. Stratospheric Sample.

( ) Values suspect due to late analysis date.

May 1957

	RASL#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (S.C.F.)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	d/m/1000 S.C.F. Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Minneapolis	5823	2234	5-11-57	65	62.1/61.7	38.8[1]	5810	6-17-57	15,900 ± 1,100	2.74 ± 0.19	105	680	159	(<1148)	58	7.72	2.74
	5876	2240	5-16-57	80	78/78.5	S	3883	6-17-57	1,160 ± 580	0.37 ± 0.15	≤16.7	47.3	22.2	≤97.1	4.78	≤20.3	4.64
	6025	2196	5-27-57	65	62.2/62.9	37.6[1]	6410	7-19-57	12,720 ± 1,100	1.98 ± 0.17	159	194	44.5	≤258	49.5	≤5.21	0.9
	6026	2255	5-27-57	90	72.5/90.4	S	1916	7-19-57	13,400 ± 680	6.99 ± 0.35	846	2133	92.8	<375	78.3	<4.79	1.18
	6039	2213	5-29-57	80	77.2/73.1	S	3952	7-19-57	2,140 ± 830	0.62 ± 0.21	43.5	295	67.7	≤95.2	28.6	≤1.23	2.37
Texas	5694	T-197	5-2-57	80	81.5	S	1948	6-17-57	1,700 ± 640	0.87 ± 0.33	76.6	280	120.7	≤179	19.3	≤3.08	6.25
	5722	T-198	5-3-57	65	66.5	S	1824	6-17-57	4,490 ± 810	2.46 ± 0.44	185	755	176	≤588	58.1	≤10.0	3.03
	5870	T-199	5-10-57	50	48.75	39.1[1]	1915	6-17-57	≤580	≤0.30	≤30	22.7	6.52	≤79	≤1.64	≤48.2	-3.98
	5871	T-200	5-14-57	50	47.5	35.9[1]	2949	6-17-57	≤620	≤0.21	≤35.7	33.4	8.47	(<187)	<2.03	—	<4.17
	5875	T-202	5-19-57	90	88.6/89.5	S	1266	6-17-57	650 ± 550	0.51 ± 0.43	≤65.2	36.2	9.86	(<176)	< 2.76	—	<3.57
	5970	T-203	5-22-57	50	49	42.0[1]	4341	7-19-57	2,130 ± 690	0.49 ± 0.16	134	109.9	25.7	(386)	7.1	—	3.61
Panama	6005	P-176	5-14-57	65	64.5/65.5	55.0[1]	1652	7-19-57	1,640 ± 740	0.99 ± 0.45	174	40.9	27	(<1180)	20.2	—	1.34
Southern Hemisphere	6006	B-185	5-14-57	65	65.3		1796	7-19-57	≤620	≤0.34	≤115	180	49.1	(<277)	32.3	<8.54	1.52
	6009	B-188	5-17-57	80	80/79.1	S	1695	7-17-57	1,030 ± 760	0.62 ± 0.46	<139	39.1	96.6	(<263)	42	<6.26	2.30
	6012	B-191	5-19-57	80	79	S	1733	7-17-57	2,300 ± 780	1.33 ± 0.45	199	473	130.1	<157	42.1	<3.49	3.09

1. Stratospheric Sample.

( ) Values suspect due to late analysis date.

June 1957

	HASL#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (S.C.F.)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	d/m/1000 S.C.F. Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Minneapolis	6331	2222	6-19-57	90	90.1/90.7	S	2283	8-26-57	6,120 ± 760	2.81 ± 0.33	92.4	96.8	14.70	(<360)	3.04	--	4.84
	6334	2235	6-27-57	50	49.6	36.3[1]	10800	8-26-57	12,810 ± 617	1.19 ± 0.057	211	211	20.3	(<258)	17.7	--	1.15
	6335	2236	6-30-57	65	62.3	44.75[1]	7886	8-26-57	14,460 ± 680	1.83 ± 0.086	96.7	555	73.0	(<430)	46.0	--	1.59
Texas	6085	T-205	6-6-57	90	90.9	S	1219	7-19-57	1,320 ± 670	1.08 ± 0.55	≤82.1	37.5	22.5	≤62.1	1.52	≤40.8	14.8
	6102	T-204	6-6-57	90	73.4/89.4	S	1028	7-19-57	1,790 ± 740	1.74 ± 0.72	152	395	125.11	≤81.4	32.1	≤ 2.54	3.9
	6103	T-206	6-7-57	80	79.7/80.1	S	2441	7-19-57	1,440 ± 690	0.59 ± 0.28	43.5	143	42.7	≤22.2	9.69	≤ 2.29	4.41
	6104	T-207	6-11-57	65	66.8/67.6	S	1736	7-19-57	3,440 ± 890	1.98 ± 0.51	163	479	237	≤80.3	52.1	≤ 1.54	4.55
	6203	T-210	6-19-57	80	80.3/81.5	S	1813	8-26-57	3,500 ± 720	1.93 ± 0.4	<120	37.9	17.6	(<165)	6.34	--	2.78
Panama	6105	P-177	6-7-57	80	78.1/79.1	S	1932	8-26-57	≤520	≤0.27	<128	<12.5	<7.66	(<329)	≤1.81	--	4.23
Southern Hemisphere	6175	B-194	6-1-57	90	88.9	S	786	8-26-57	3,790 ± 540	4.82 ± 0.69	<333	968	164	≤248	57.9	≤ 4.28	2.83
	6176	B-195	6-2-57	65	66.2/63.5	53.9[1]	1265	8-26-57	1,410 ± 450	1.11 ± 0.36	112	196	12.58	388	4.47	86.8	2.81
	6177	B-196	6-2-57	90	93.3/95.9	S	1278	8-26-57	2,080 ± 540	1.58 ± 0.42	223	406	149.4	< 421	47.3	8.9	3.16
	6305	B-198	6-13-57	90	93.5	S	949	8-26-57	2,030 ± 460	1.08 ± 0.48	333	138	20.6	(<415)	< 3.69	--	-5.58
	6306	B-199	6-14-57	80	77.1/81.1	S	1788	8-26-57	1,748 ± 540	0.98 ± 0.30	<87	301	25.7	≤160	28.5	≤ 5.61	0.90
	6307	B-200	6-15-57	50	49.3	40.1[1]	1926	8-26-57	1,870 ± 540	0.97 0.28	125	105.5	38.8	(<139)	4.93	28.2	7.87

1. Stratospheric Sample.

( ) Values suspect due to late analysis.

July 1957

	NASL#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (S.C.F.)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	d/m/1000 S.C.F. Zr^{95}	Ce^{144}	Ce^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Ce^{137}/Sr^{90}
Minneapolis	6426	2237	7-9-57	90	88.1/88.7	S	1738	8-26-57	1,210 ± 670	0.70 ± 0.38	< 79.2	26.3	18.4	< 99.8	<1.29	<77.4	=14.3
	6427	2241	7-11-57	50	50.5/50.7	46.3[1]	7174	9-17-57	7,330 ± 860	1.02 ± 0.12	222	250	17.0	112	7.04	15.9	2.41
	6428	2242	7-11-57	65	64.7/62.4	46.3[1]	7720	9-17-57	25,490 ± 1,410	3.30 ± 0.18	714.3	533	108.1	<174	52.4	<3.32	2.06
	6429	2244	7-15-57	80	76.0/76.4	S	4361.7	9-17-57	2,140 ± 690	0.49 ± 0.16	<28.4	300	64.0	<162	21.8	<7.44	2.94
	6434	2246	7-23-57	65	59.9/61.7	47.3[1]	2145	9-17-57	10,760 ± 800	4.95 ± 0.37	304	1386	363	< 390	122	< 3.2	2.98
	6566	2247	7-29-57	90	90.0/90.8	S	2288	9-17-57	<630	<0.28	73.2	38.1	8.17	(<124)	<1.75	—	> 4.67
Texas	6406	T-212	7-7-57	90	87.0/87.4	S	1225	8-26-57	3,320 ± 500	2.71 ± 0.41	343	234	31.4	557	10.6	52.5	2.96
	6408	T-214	7-11-57	80	80.8/81.5	S	1809	8-26-57	3,570 ± 560	1.97 ± 0.31	119	428	198	<332	42.0	7.9	4.71
	6425	T-215	7-13-57	50	48.9	47.0[1]	1850	8-26-57	3,020 ± 480	1.60 ± 0.25	547	373	1.96	(<473)	<2.38	—	=0.82
Southern Hemisphere	6456	B-201	7-7-57	65	64.8/65.5		819	9-23-57	6,810 ± 940	8.32 ± 1.15	716	1380	370	1410	122	11.5	3.03
	6457	B-202	7-10-57	90	92.5/92.7	S	973	9-17-57	≤690	≤0.71	<272	99.5	16.8	(<339)	<1.03	—	=16.3
	6458	B-204	7-10-57	80	78.1/74.4	S	2173	9-17-57	2,600 ± 850	1.20 ± 0.41	<53.9	294	102.6	<126	21.3	< 5.97	4.86
	6459	B-205	7-13-57	50	48.8/48.9	47.9[1]	1849	9-17-57	2,017 ± 650	1.06 ± 0.33	558	293	6.99	<44.3	1.18	< 37.5	5.92

1. Stratospheric Sample.

( ) Values suspect due to late analysis.

August 1957

	NASL#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (S.C.F.)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	d/m/1000 S.C.F. Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Minneapolis	6605	2248	8-2-57	50	48.6/49.1	45.7[1]	5174	9-17-57	6,064 ± 800	1.17 ± 0.15	220	165	11.90	89.8	3.07	29.2	3.88
	6610	2249	8-5-57	90	89.6/91.5	s	2151	9-17-57	641 ± 570	0.26 ± 0.23	245.7	35.4	8.91	<62.3	<1.22	51.0	7.30
	6661	2253	8-10-57	90	88.9	s	2646	9-17-57	<630	≤0.24	<27.6	19.7	5.30	(<180)	<1.32	--	4.02
	6695	2256	8-20-57	65	64.0	41.1[1]	12630	9-17-57	20,390 ± 990	1.61 ± 0.08	37.1	462	161	<118	54.2	<2.18	2.97
Texas	6653	T-217	8-6-57	65	64.9	50.6[1]	1660	9-17-57	4,670 ± 690	2.81 ± 0.42	126	643	161	<136	52.1	2.61	3.09
	6654	T-218	8-7-57	90	89.4/91.8	s	1061	9-17-57	3,100 ± 710	2.92 ± 0.67	348	303	33.5	(497)	11.6	--	2.89
Southern Hemisphere	6697	B-207	8-3-57	65	64.0/66.0		1232	9-17-57	1,100 ± 720	0.89 ± 0.58	160	221	122.8	<196	35.7	<5.49	3.44
	6698	B-209	8-5-57	50	49.0		1816	9-23-57	2,080 ± 630	1.14 ± 0.35	310	223	17.2	(<216)	3.73	--	4.61
	6700	B-211	8-8-57	80	79.2/79.8	s	1797	9-17-57	<540	≤0.30	60.7	11.9	7.8	<77.4	1.11	69.7	7.03
	6701	B-214	8-18-57	90	90.1	s	993	9-17-57	2,390 ± 700	2.41 ± 0.70	<67.6	156	75.2	<109	17.6	<6.19	4.27

1. Stratospheric Sample.

( ) Values suspect due to late analysis.

September 1957

	EASL#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (S.C.F.)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	d/m/1000 S.C.F. Ba^{140}	d/m/1000 S.C.F. Zr^{95}	d/m/1000 S.C.F. Ce^{144}	d/m/1000 S.C.F. Ce^{137}	d/m/1000 S.C.F. Sr^{89}	d/m/1000 S.C.F. Sr^{90}	Sr^{89}/Sr^{90}	Ce^{137}/Sr^{90}
Minneapolis	6805	2263	9-4-57	50	46.6/45.9	38.9[1]	2258	9-23-57	5,440 ± 770	2.41 ± 0.34	≤24.5	272	400	38.1	<179	28.3	<63.4	1.35
	6827	2265	9-6-57	80	77.5/77.2	8	2917	9-23-57	2,180 ± 820	0.72 ± 0.28	≤108	112	134	55.9	<13.0	13.9	<0.94	4.02
	6849	2268	9-11-57	65	65.2	39.8[1]	3648	9-23-57	6,840 ± 740	1.88 ± 0.20	≤11.4	58.4	510	198	56.9	58.5	0.97	3.38
	6932	2269	9-23-57	65	63.0	32.6[1]	4203	10-4-57	4,470 ± 880	1.06 ± 0.21	≤27.1	54.5	386	124.0	257	42.3	5.61	2.93
Texas	6758	T-221	9-4-57	90	90.1	8	1053	9-23-57	5,090 ± 600	4.87 ± 0.58	≤107	214	109	108.7	≤37.8	20.8	1.82	5.22
	6850	T-222	9-6-57	80	80.5	8	1805	9-23-57	6,330 ± 730	3.51 ± 0.40	≤423	140	139	283	<95.4	53.5	1.74	5.29
	6851	T-223	9-11-57	65	64.7	50.9[1]	1802	9-23-57	5,510 ± 710	3.06 ± 0.39	≤286	197	564	205	< 113	53	< 2.13	3.87
	6914	T-224	9-13-57	50	49.3/50.7	44.0[1]	1654	10-4-57	2,230 ± 640	1.35 ± 0.39	≤142	137	219	32.1	64.9	8.56	7.58	3.75
Southern Hemisphere	6879	B-216	9-6-57	65	64.2		1586	9-26-57	1,800 ± 640	1.13 ± 0.40	≤59.7	64.4	196	94.4	92.5	25.2	3.67	3.75
	6881	B-219	9-11-57	80	80.2	8	2288	9-26-57	930 ± 540	0.41 ± 0.24	≤51.4	≤24.2	26.3	11.9	<33.0	2.58	<12.8	4.61

1. Stratospheric Sample.

October 1957

	Radiff	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (S.C.F.)	C-date	Total Activity d/m/sample	d/m/S.C.F.	d/m/1000 S.C.F. Ba^{140}	Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Minneapolis	6980	2276	10-2-57	50	48.4/49.2		4087	10-9-57	1,220 ± 610	0.30 ± 0.15	10.2	80.6	63.8	7.25	22.4	2.72	8.24	2.66
Texas	6981	T-225	10-1-57	50	49.8	48.5[1]	1604	10-9-57	2,910 ± 660	1.81 ± 0.41	113	183	159	90.4	141.9	2.28	19.7	39.6
	6982	T-226	10-3-57	90	91.25/90.75	s	1062	10-9-57	4,950 ± 790	4.28 ± 0.74	218	185	169	38.2	111	4.66	23.8	8.2
	6996	T-227	10-4-57	80	82.5	s	1585	10-25-57	3,501 ± 110	2.21 ± 0.069	572	147	366	53.2	81.7	16.4	5.16	3.24
	6997	T-228	10-5-57	65	63.5		1995	10-25-57	6,285 ± 120	3.21 ± 0.061	241	171	564	146	186	36.3	5.12	4.02
Southern Hemisphere	7059	S-225	10-8-57	90	89.5	s	856	10-25-57	≤470	≤0.55	<23.8	69.6	32.2	29.2	(<42.3)	<2.34	18.1	12.5
	7060	S-224	10-9-57	80	80.2	s	1832	10-25-57	621 ± 100	0.34 ± 0.054	≤10.5	≤96	45.3	24.3	≤12.3	3.77	≤3.26	6.44
	7063	S-227	10-11-57	65	67.2		1790	10-25-57	925 ± 120	0.52 ± 0.067	12.7	50.9	173	137.7	88.4	22	4.02	6.26

1. Stratospheric Sample.

( ) Values suspect due to late analysis date.

November 1957

	Hasl #	Flight #	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (S.C.F.)	C-date	Total Activity d/m/sample		d/m/S.C.F.	d/m/1000 S.C.F. Ba^{140}	Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Minneapolis	7257	2299	11-25-57	80	78.4/79.0	8	806	12-12-57	2,590 ±	810	3.21 ± 1.00	218	247	508	100	343	29.3	11.7	3.43
	7258	2301	11-30-57	65	63.7/64.3		3617	12-12-57	3,780 ±	630	1.04 ± 0.17	73.7	92.8	200	50.5	110	14.6	7.53	3.46
Texas	7234	T-231	11-18-57	80	81.0/80.2	8	5554	11-26-57	3,720 ±	680	0.66 ± 0.12	—	14.3	287	94.1	7.04	25.6	0.28	3.68
	7235	T-232	11-18-57	50	47.5		2620	11-26-57	16,080 ±	900	6.62 ± 0.37	1380	735	548	33.9	139	9.92	14.0	3.42
	7236	T-236	11-27-57	65	66.0/65.5		1770	12-12-57	12,600 ±	870	7.11 ± 0.49	419	584	1520	172	520	45.2	11.5	3.80
	7240	T-235	11-23-57	65	66		1766	1-7-58	44,200 ±	890	25.0 ± 0.50	—	2517	2011	266	2998	714.2	35.0	3.52
Southern Hemisphere	7301	S-231	11-24-57	80	80/79.5	8	1900	12-23-57	841 ±	630	0.42 ± 0.32	<16.9	<11.8	61.8	38.6	<11.5	9.79	1.17	3.95

December 1957

	Hasl#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (S.C.F.)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	d/m/1000 S.C.F. Ba^{140}	Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Minneapolis	7259	2302	12-4-57	50	46.7/47.5		1865	12-12-57	27,570 ± 1,380	6.46 ± 0.32	216	878	858	61.9	395	23.4	16.8	2.64
	7272	2304	12-12-57	80	81.1/81.5	8	1994	1-7-58	14,100 ± 890	8.84 ± 0.56	—	54.9	60.2	15.4	53.8	3.78	14.2	4.07
	7341	2305	12-21-57	65	65.45		3406	1-7-58	28,380 ± 690	8.33 ± 0.20	—	560	799	179	804	55.9	14.4	3.20
	7425	2303	12-19-57	90	88.1/88.6	8	1463	1-16-58	2790	±0.54	14.0	56.2	53.0	12.3	70.8	<3.08	>22.7	>3.99
Texas	7269	T-237	12-9-57	90	92.7	8	1001	12-16-57	1,270 ± 640	1.27 ± 0.64	<18.1	172	lost	58	<12.9	<4	10.7	-14.5
	7277	T-236	12-9-57	80	80.4	8	1750	12-16-57	1,400 ± 660	0.80 ± 0.38	21.2	28.9	159	60.7	<61.8	8.77	<7.04	± 6.92
	7278	T-239	12-9-57	50	48.8	48.0[1]	1712	12-16-57	1,270 ± 600	0.74 ± 0.35	<19.8	84.9	86.1	11.7	61.7	3.04	20.3	3.85
	7296	T-242	12-11-57	65	62.4		2085	12-23-57	22,760 ± 3,845	10.9 ± 1.84	234	675	1005	53.2	941	54.7	17.2	0.97
Panama	7288	P-211	12-2-57	90	89.5/88.3	8	1153	12-16-57	650 ± 630	0.57 ± 0.56	<23.4	54.7	317	65.6	865	25	11.5	2.76
	7297	P-212	12-4-57	65	65.9/65.5		1740	12-23-57	20,050 ± 3,020	11.5 ± 1.74	584	138	1164	124	1370	44.1	21.4	1.93
Southern Hemisphere	7484	S-234	12-10-57	80	81.2/80.3	8	1821	1-16-58	550	±0.30	<24.4	<14.8	158	105.6	<24.8	23.1	<1.07	4.58
	7485	S-236	12-12-57	65	65.5/65.8		1571	1-16-58	560	±0.36	<15.1	31.6	183	71.0	55.9	23.9	2.34	2.97
	7487	S-239	12-14-57	50	51.5/51.2		2744	1-16-58	560	±0.20	<7.1	5.26	2.81	2.00	7.31	1.42	5.15	1.41

1. Stratospheric Sample.

January 1958

	Sample	Flight	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume S.C.F.	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	d/m/1000 S.C.F. Ba^{140}	Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Minneapolis	7514	2309	1-10-58	65	64.2		3165	2-1-58	8,439 ± 950	2.66 ± 0.30	83.6	273	513	124	374	39.8	9.4	3.12
	7518	2310	1-12-58	90	90/85.6		1546	2-1-58	947 ± 560	0.61 ± 0.36	<41.51	40.6	169	76.8	27.1	15.9	1.70	4.85
	7554	2311	1-22-58	80	77.7/78.0		1486	2-2-58	1,178 ± 576	0.79 ± 0.38	5300	28.3	146	35.5	20.9	15.2	1.38	2.34
Texas	7492	T-214	1-7-58	80	79.6/81.1		1707	2-1-58	1,200 ± 770	0.70 ± 0.45	<9.95	33.2	121.8	39.5	55.2	7.91	6.98	4.99
	7493	T-215	1-8-58	90	90.1		1139	2-1-58	1,401 ± 710	1.23 ± 0.62	<12.2	84.6	199	54.9	53.5	11.9	<4.5	4.61
	7526	T-218	1-17-58	65	65.1		1049	2-1-58	12,371 ± 740	11.79 ± 0.70	211	1065	1520	221.	1062	72.4	14.7	3.09
Panama	7491	P-216	1-5-58	80	78.9/81.1		1708	2-1-58	1,287 ± 590	0.75 ± 0.34	30.2	61.1	468	22.2	99.1	67.3	1.47	0.33
	7522	P-217	1-13-58	90	89.4/91.3		782	2-1-58	1,294 ± 650	1.65 ± 0.83	<35.3	52.8	270	46.4	<122	26.7	4.57	1.70
South America	7556	S-214	1-8-58	90	90.1/92.0		951	1-2-58	2466	2.59	22000	49.5	55.7	84.6	22.4	2.31	9.68	(36.6)
	7557	S-216	1-10-58	65	64.4/65.2		1622	1-2-58	4510	2.31	2860	48.8	74.4	31.8	28.4	11.6	2.45	2.74

February 1958

	NASL#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (ft^3)	Total Activity C-date	Total Activity d/m/sample	Total Activity $d/m/ft^3$	d/m/1000 ft^3 Ba^{140}	Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Minneapolis	7623	2325	2-5-58	90	88.6/90.5	8	1434	5-1-58	311 ± 98	0.22 ± 0.07	3210	73.1	91.3	16.5	88.1	14.3	5.62	1.15
	7624	2326	2-7-58	80	77.6/77.1	8	1317	4-28-58	1,690 ± 120	1.28 ± 0.09	5040	188	342	78.2	60	12.7	4.72	6.15
	7643	2327	2-13-58	50	45.5		3947	5-3-58	9,320 ± 220	2.36 ± 0.06	560	855	722	76.0	339	31.2	10.9	2.44
	7653	2328	2-20-58	65	63.9/64.15		3457	4-17-58	1,293 ± 455	0.37 ± 0.13	4470	31.5	184	26.9	37.1	24.7	1.5	1.09
Panama	7642	P-226	2-10-58	80	81.0/79.6	8	1823	5-3-58	1,950 ± 120	1.07 ± 0.06	1910	38.4	143	169	63.8	53	1.20	3.19
South America	7645	B-248	2-3-58	65	65.4/66.0		1489	4-17-58	970 ± 1699	0.66 ± 0.31	28700	171	212	118	70.2	25.7	2.73	4.59
	7646	B-251	2-9-58	80	79.2/79.7	8	1936	5-13-58	635 ± 30	0.33 ± 0.02	2920	30.7	93.9	43	22.8	14.2	1.60	3.02
	7647	B-252	2-10-58	90	85.5/89.1	8	1052	4-2-58	345	0.33	4390	47	32.2	8.27	7.40	4.52	1.64	1.83

March 1958

	Rad'g	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (ft^3)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/ft^3	d/m/1000 ft^3 Ba^{140}	Zr^{95}	Ce^{144}	Ce^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Ce^{137}/Sr^{90}
Minneapolis	7712	2329	3-6-58	50	48.7		5486	3-13-58	12,630 ± 933	2.30 ± 0.17	5.85	198	165	21.8	154	24.4	6.32	1.01
	7713	2330	3-12-58	65	63.4/63.7		3594	3-24-58	5,740 ± 40	1.6 ± 0.01	1360	146	650	105	lost	lost	—	—
	7710	2331	3-20-58	80	78.1/77.4	8	1634	3-13-58	425 ± 27	0.26 ± 0.02	501	48.5	143	38.7	57.5	12.9	4.46	3.01
	7778	2335	3-26-58	90	92.8	8	1294	4-1-58	993 ± 16	0.46 ± 0.02	2103	170	180	19.1	100	0.10	960	0.005
Texas	7666	T-255	3-3-58	90	91.9/87.6	8	1480	4-2-58	1,602 ± 538	1.08 ± 0.36	734	lost	270	41.3	9.51	9.03	1.05	4.57
	7727	T-257	3-9-58	65	65.1		1854	4-17-58	4,760 ± 462	2.57 ± 0.25	10900	lost	748	129	0.0	14.0	—	9.23
Panama	7684	P-229	3-1-58	80	80.5/80.7	8	1758	4-2-58	2,219 ± 608	1.26 ± 0.34	5460	89.7	323	130	78.8	48.1	1.64	2.7
South America	7714	S-255	3-4-58	90	91.4/92.0	8	903	4-1-58	236 ± 17	0.26 ± 0.02	3620	209	60.0	22.6	0.0	22.1	—	1.02
	7715	S-257	3-6-58	90	88.9/89.5	8	1080	4-17-58	<521	0.48	3540	19.6	53	7.27	28.7	7.55	3.8	0.96
	7716	S-258	3-7-58	80	78.1/79.1	8	2089	5-13-58	620 ± 20	0.31 ± 0.01	1540	<254	76.5	39.6	32.6	14	2.33	2.83

April 1958

	HASL#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (ft^3)	Total Activity C-date	Total Activity d/m/sample	Total Activity $d/m/ft^3$	d/m/1000 ft^3 Ba^{140}	Zr^{95}	Ce^{144}	Ce^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Ce^{137}/Sr^{90}
Minneapolis	7805	2336	4-7-58	90	90.1	S	1443	5-8-58	150 ± 10	0.104 ± 0.007	2571	54.9	113	22.9	38.4	12.8	3.0	1.78
	7806	2337	4-8-58	80	74.4/77.9	S	1502	6-28-58	340 ± 10	0.23 ± 0.007	309	121	172	42.9	61.6	16.5	3.74	2.61
	7807	2338	4-9-58	50	46.5/47.3		3699	6-29-58	7,800 ± 100	2.13 ± 0.03	1410	3960	1420	48.2	571	26.1	21.9	1.85
	7862	2339	4-23-58	65	61.4/64.7		2750	7-11-58	2,370 ± 50	0.86 ± 0.02	194	556	265	138	269	52.9	5.08	2.61
Texas	7793	T-259	4-1-58	90	90.2/90.7	S	1082	6-19-58	480 ± 20	0.444 ± 0.02	536	119	224	55.4	18.6	22.6	0.82	2.45
	7794	T-260	4-2-58	80	79.9	S	1887	6-19-58	168 ± 8	0.089 ± 0.004	44.5	15.9	95.1	30.5	12.9	8.9	1.45	3.42
	7795	T-261	4-3-58	65	64.7		1923	6-27-58	3,270 ± 80	1.70 ± 0.04	91.5	910	321	130	267	35.6	7.48	3.64
	7804	T-263	4-8-58	50	49.4		1780	6-27-58	570 ± 20	0.32 ± 0.01	146	454	186	9.18	68.2	4.3	15.9	2.14
Panama	7826	P-241	4-1-58	90	91.4/93.5	S	920	7-11-58	221 ± 9	0.24 ± 0.01	495	37.9	231	92.9	5.28	47.3	0.11	1.96
	7863	P-244	4-11-58	65	65.0		1892	7-11-58	1,110 ± 20	0.59 ± 0.01	139	563	197	66.9	134	32	4.18	2.09
South America	7808	S-263	4-3-58	65	65.5		1887	6-29-58	151 ± 6	0.08 ± 0.003	230	68.7	67.4	11.5	24.3	5.88	4.13	1.95
	7809	S-265	4-4-58	80	79.1/79.5	S	1968	7-8-58	443 ± 9	0.22 ± 0.004	241	46.4	256	123	23.7	30.5	0.78	4.02
	7810	S-266	4-5-58	90	92.7	S	867	7-8-58	38 ± 6	0.044 ± 0.007	492	36.4	65.5	27.7	1.82	12.3	0.15	2.25

June 1958

	Hasl#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (ft^3)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/ft^3	d/m/1000 ft^3 Ba^{140}	Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Ce^{137}/Sr^{90}
Minneapolis	8176	2364	6-7-58	90	90.7/91.4	8	1454	7-18-58	1,100	0.76	14.3	37.3	75.4	5.84	15.3	6.09	2.51	0.96
	8177	2365	6-11-58	50	46.1		3644	7-17-58	10,950	3.00	63.4	295	548	14.5	332	15.8	21.0	0.92
	8188	2367	6-17-58	80	76.9	8	1576	10-7-58	700	0.44	<8.39	<11.9	85.0	28.8	<26.5	14.5	<1.83	1.99
	8302	2372-4	6-27-58	65	53.5/66.3		3537	7-10-58	15,600 ± 872	4.41 ± 0.25	<120	207	640	68.4	419	37.6	11.1	1.82
Texas	8098	T-275	6-3-58	80	79.9/80.3	8	1951	7-19-58	1,200	0.62	23.9	26.2	105	51.5	27.8	11.3	2.46	4.56
	8099	T-277	6-5-58	90	88.8/89.5	8	1110	7-18-58	2,550	2.3	140	80.6	lost	39.2	<77.2	18.0	>4.29	2.18
	8175	T-278	6-7-58	65	65.0/65.3		1354	7-8-58	2,500	1.85	46.6	196	291	57.6	228	9.3	24.1	6.19
Panama	8072	P-251	6-2-58	65	64.5/64.8		1821	8-6-58	10,550	5.79	887	700	1160	80.7	1047	42.6	24.6	1.89
	8178	P-252	6-6-58	80	79.5/81.7	8	1766	7-17-58	9,350	5.29	90.9	684	1197	24.2	420	67.4	6.23	0.36
South America	8185	S-277	6-4-58	65	63/64.1	55,216[1]	1860	10-10-58	1,850	0.99	<23.1	120	422	84.1	86.8	30.9	2.81	2.72
	8186	S-279	6-8-58	80	79.1	8	1890	10-11-58	500	0.26	<10.4	<8.52	24.9	15.2	<25.6	4.47	<5.73	3.40
	8187	S-281	6-13-58	80	78.1/78.6	8	1712	10-13-58	300	0.18	<10.9	<11.4	45.7	21.0	<17.3	9.02	<1.92	2.33

1. Stratospheric Sample.

July 1958

	EASL#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (ft^3)	Total Activity C-date	Total Activity d/m/sample		Total Activity d/m/ft^3	d/m/1000 ft^3 Ba^{140}	Sr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Texas	8323	T-280	7-2-58	80	81.5/81.7	s	1665	10-18-58	<800		<0.48	98.3	<29	98	25.2	<89.7	16.2	<5.54	1.56
	8324	T-281	7-3-58	65	67		1651	10-18-58	2,950 ±	150	1.79 ± 0.27	94.6	227	595	149	497	39.1	12.4	1.26
	8367	T-287	7-18-58	90	86.5	s	1078	9-23-58	251 ±	8	0.234 ± 0.007	<157	68.1	114	45.9	51.9	15.8	3.28	2.91
South America	8327	B-283	7-7-58	65	69.1/70.2	54. 823	1299	---	---		---	<181	<296	163	40	104	33.1	3.16	1.21
	8329	B-285	7-9-58	90	89.4/89.7	s	1073	---	---		---	<184	<260	171	36.3	18.5	21.7	0.75	1.47
	8330	B-286	7-10-58	65	62.5/63.5	58. 058	1880	9-18-58	514 ±	16	0.27 ± 0.01	68.0	157	323	54.8	42.3	25.2	1.68	1.38
	8331	B-287	7-11-58	80	76.4/79.6	s	1615	9-17-58	578 ±	17	0.36 ± 0.01	67.1	127	318	56.0	52.1	34.4	1.52	1.63

August 1958

	Event	Flight	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (ft³)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/SCF	d/m/1000 SCF Ba^{140}	Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Sioux City	8584	I-011	8-2-58	90	90.2/88	8	1067	9-07-58	74 ± 6	0.069 ± 0.006	(2010)	lost	67.0	14.5	229	14.0	16.4	1.04
	8585	I-012	8-3-58	65	65.75/65.5		1681	9-03-58	1,610 ± 39	0.96 ± 0.02	<46.1	407	679	106	268	30.0	8.91	3.53
	8625	I-014	8-7-58	50	48.5	44	2628	8-15-58	902 ± 578	0.34 ± 0.22	<25.1	20.1	18.0	6.48	57.6	<1.95	>29.5	> 3.41
	8626	I-015	8-9-58	80	80	8	1912	8-15-58	1,856 ± 563	0.96 ± 0.21	<21.7	13.6	85.8	31.1	84.8	11.2	2.21	2.78
Texas	8393	T-289	8-1-58	50	49.5	49.5	1969	9-01-58	7,500 ± 170	3.71 ± 0.09	2200	2570	714	34	192	18.3	10.5	1.87
	8394	T-290	8-2-58	90	91.75/91.0	8	1017	8-15-58	1,047 ± 510	1.05 ± 0.54	<48.8	28.8	186	68.8	27.6	16.2	1.70	4.24
	8396	T-293	8-5-58	80	81.0/80.5	8	1786	8-15-58	1,804 ± 561	0.67 ± 0.21	(<387)	15.5	157	53.2	32	23.8	1.34	2.24
Panama	8397	P-258	8-1-58	65	65.1/64.2		1686	8-15-58	731,000 ± 4,900	145 ± 2.9	8100	1530	7190	608	59,400	747	79.5	0.81
Brazil	8600	B-293	8-5-58	65	65.2/64.6	52.1	1715	8-26-58	14,475 ± 612	8.44 ± 0.36	144	725	1,400	164	1160	68.5	16.6	9.88
	8601	B-291	8-7-58	80	80.7/78.5	8	1605	8-26-58	977 ± 397	0.61 ± 0.25	<50.1	567	63.1	46.4	24	7.61	3.15	6.1
	8602	B-290	8-5-58	90	93.8/92.4	8	911	8-26-58	991	0.43	<71.2	56.8	130	67	205	19.6	<10.4	3.42

September 1958

	Rad'd	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (ft^3)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	d/s/1000 ft^3 Ba^{140}	Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}	"S"	"S"/Sr^{90}
Sioux City	8681	I-17	9-1-58	50	49.5	45	1962			Sample Lost										
	8667	I-18	9-7-58	80	78.75/80	8	1915	9-26-58	451 ± 543	0.24 ± 0.28									116	
	8687	I-19	9-8-58	65	61.5/61.75		2553	9-26-58	777 ± 493	0.30 ± 0.19									59.9	
Tampa	8679	T-295	9-5-58	80	80.5/79.75	8	1797.7	9-26-58	1,414 ± 512	0.79 ± 0.28										
Brazil	8700	B-294	9-2-58	90	91.5/96	8	813	9-26-58	935 ± 627	1.15 ± 0.77	<252	<89.2	505	29.5	49.2	80.9	2.35	1.43	<26.1	1.25
	8702	B-295	9-3-58	85	82.7/83.2	8	1512.8	9-26-58	347 ± 520	0.23 ± 0.34	<117	<51	198	45.3	26.7	56	0.69	1.26	14.5	0.260
	8701	B-298	9-4-58	65	65.3/65.9		1225	9-26-58	3,016 ± 599	2.46 ± 0.49	170	533	1652	65.8	131	38.3	3.42	1.72	82.8	2.16

October 1958 *

	Sample	Flight No.	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (ft^3)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/s.c.f.	d/m/1000 ft^3 Sr^{140}	Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}	*F	*F/Sr^{90}
Mount Clay	8811	I-23	10-11-58	65	64.5/64.25	8	1878	11-5-58	3,414 ± 518	1.73 ± 0.26										
	8825	I-27	10-18-58	90	90/89.5	8	1961	11-5-58	486 ± 476	0.46 ± 0.45	<380	32.1	95.2		<11.5	14.2	2.92		38.5	2.71
Texas	8824	T-302	10-17-58	65	65.75/65.25		1814	11-5-58	5,625 ± 515	3.01 ± 0.28										
	8823	T-301	10-16-58	80	79.5/79.0		2101	11-5-58	0.0 ± 425	0.0 ± 0.29	<1190	21.5	100		25.9	12.7	2.42		132	12.3
Canal Zone	8829	P-204	10-8-58	65	66.1/66.0	8	1674	11-5-58	95,598 ± 1,600	57.1 ± 0.84										
Brazil	8817	B-302	10-6-58	65	67.0/66.5	8	1535	11-5-58	4,509 ± 515	3.38 ± 0.38										
	8819	B-308	10-8-58	80	83.5/82.5	8	1686	11-5-58	12,988 ± 784	8.74 ± 0.53	<1770	589	2650		432	140	2.76		140	1.0
	8820	B-301	10-7-58	90	91.5/90	8	863	11-5-58	0 ± 670	0.0 ± 0.78	<2580	<27	40.2		<58.9				48.4	

November 1958

Town City	Build	Flight	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (ft^3)	C-date	Total activity d/m/sample	d/m/ft^3	d/m/1000 ft^3 Ba^{140}	Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}	"S"	"S"/Sr^{90}
Texas	8927	T-305	11-1-58	90	88.25/87.5	S	1110	12-11-58	487 ± 750	0.44 ± 0.68	<165	132	170		60.6	18.3	3.31		65.4	3.57
Canal Zone	8990	P-066	11-7-58	65	65.1/64.75		1685	12-11-58	189,000 ± 1650	76.4 ± 0.98										
	9017	P-069	11-16-58	90	90.75/88.25	S	1118	12-11-58	7,796 ± 817	6.97 ± 0.73	< 98	461	1830		29.5				8.8	
	9036	P-070	11-19-58	80	82.4/80.8	S	1535	1-5-59	20,300 ± 1130	13.2 ± 0.74	483	2100	7340	607	3400	289	12.1	2.10	143	0.49
Brazil	9013	B-301	11-4-58	80	83.6/83	S	1958	12-11-58	3,530 ± 657	1.81 ± 0.34	<152	236	546		98.1				81.6	
	9014	B-305	11-5-58	90	93.5/92.4	S	853	12-11-58	515 ± 704	0.60 ± 0.82	<205		575		40.6	62.2	>0.65		159	2.56
	9015	B-309	11-9-58	65	66.6/65		1617	12-11-58	377 ± 696	0.23 ± 0.40										

December 1958

	NASL#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (ft^3)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/ft^3	d/m/1000 ft^3 Ba^{140}	Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Ce^{137}/Sr^{90}	"S"	"S"/Sr^{90}
Iowa City	9165	I-40	12-27-58	50	49.2/48.75	35	2163	2-12-59	12,900 ± 618	5.24 ± 0.25										
	9230	I-42	12-31-58	80	81.75/80.5	8	1774	2-12-59	2,658 ± 180	1.49 ± 0.27										
Texas	9070	T-307	12-1-58	90	89.8/88.5	8	1239	1-5-59	1,110 ± 64	0.896 ± 0.56	477	148	1210	15.5	98.8	12.7	7.77	1.24	29.1	2.29
	9069	T-311	12-5-58	65	63.8/63.2		2218	1-5-59	8,750 ± 906	3.94 ± 0.41	935	513	1290	168	872	61.3	14.2	2.52	451	7.36
	9081	T-312	12-11-58	80	80.5/80.0	8	2030	1-5-59	5,270 ± 660	2.54 ± 0.32	143	1160	1580	82.5	89.1	15.5	5.74	1.46	37.5	2.41
Panama Canal Zone	9066	P-276	12-8-58	65	65.75		1710	1-5-59	51,900 ± 1,500	29 ± 0.86	1410	6440	7350	436	6910	173	40	2.52	8589	48.5
	9092	P-277	12-12-58	90	92.6/91	8	946	2-12-59	2,162 ± 532	2.28 ± 0.56										
Brazil	9073	B-312	12-4-58	65	68.2/67.8		1097	1-5-59	2,050 ± 560	1.85 ± 0.51	685	653	1130	116	586	27.8	18.9	4.16	310	11.2
	9071	B-315	12-6-58	80	81.0/78.4	8	1759	1-5-59	718 ± 617	0.408 ± 0.349										
	9072	B-316	12-7-58	90	88.1/82.1	6	958	1-5-59	2,240 ± 584	2.34 ± 0.61										

January 1959

	RAM #	Flight #	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (ft^3)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/ft^3	d/m/1000 ft^3 Ba^{140}	Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Iowa City	9270	I-44	1-8-59	90	89	8	1092	2-24-59	1,367 ± 627	1.25 ± 0.57								
	9313	I-45	1-22-59	80	81/76.8	8	1132	2-24-59	5,478 ± 652	4.84 ± 0.58								
Texas	9272	T-316	1-10-59	80	80.6/80.1	8	2041	2-24-59	2,925 ± 620	1.43 ± 0.30								
	9312	T-317	1-2-59	90	95.9/95.0	8	685	2-24-59	4,341 ± 701	6.34 ± 1.02								
Brazil	9362	B-320	1-16-59	80	79.3/77.0	8	2141	2-24-59	0 ± 724	0.0 ± 0.34								
	9363	B-322	1-20-59	65	64.4		1592	2-24-59	2,450 ± 612	1.54 ± 0.38								
	9364	B-324	1-22-59	90	91.6/87.7	8	1700	2-24-59	1,030 ± 562	0.60 ± 0.33								

February 1959

	MASL#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (ft^3)	Total Activity C-date	Total Activity d/m/sample	Total Activity $d/m/ft^3$	d/m/1000 ft^3 Ba^{140}	Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}
Iowa City	9666	I-48	2-26-59	50	48.5/48	31	2171	3-24-59	5,271 ± 536	2.43 ± 0.25								
Texas	9455	T-317	2-4-59	90	90.5/89.5	S	1025.	Lost ----										
	9456	T-318	2-6-59	80	81.4	S	1685	2-24-59	9,688 ± 679	5.75 ± 0.40								
	9530	T-320	2-15-59	50	50.5/49.8	39.0 K	2345	3-24-59	4,699 ± 433	2.00 ± 0.18								
	9531	T-321	2-16-59	65	65.8/65.3	S	1760	3-24-59	6,350 ± 570	3.61 ± 0.32								
Brazil	9532	B-325	2-3-59	65	66.0/65.0	54.1K	1810	3-24-59	0.0 ± 421	0.0 ± 0.25								
	9533	B-326	2-4-59	80	80.1/79.2	S	1834	3-24-59	7,679 ± 699	4.19 ± 0.35								
	9534	B-328	2-7-59	90	92.0/89.25	S	1003	3-24-59	1,003 ± 462	1.00 ± 0.46								

March 1959

	Hash#	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (ft³)	Total Activity C-date	Total Activity d/m/sample	Total Activity d/m/S.C.F.	d/m/S.C.F. Ba^{140}	Zr^{95}	Ce^{144}	Ce^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Ce^{137}/Sr^{90}
Iowa City	9667	I-49	3-1-59	90	91/89.5	E	896.2	3-24-59	777 ± 433	0.87 ± 0.48								
	9787	I-51	3-30-59	65	66.25/65.3		1849											
Texas	9665	T-323	3-3-59	50	49.8/47.2	40	2537	3-24-59	2,864 ± 439	1.85 ± 0.19								
	9686	T-326	3-9-59	80	81.2/80.8	E	1689	3-24-59	5,662 ± 617	3.35 ± 0.36								
	9688	T-325	3-7-59	80	81.2/80.8	E	1308	3-24-59	2,313 ± 464	1.77 ± 0.35								
	9738	T-327	3-12-59	65	64.7/63.8	E	1885											
	9739	T-328	3-17-59	80	82.0/80.8	E	1896											

April 1972

	Sample	Flight#	Flight Date	Nominal Altitude	Actual Altitude	Tropopause Height	Volume (ft^3)	Total Activity			g/s/1000 ft^3										
								S-date	d/m/sample	d/m/1000 ft³	Ba^{140}	Zr^{95}	Ce^{144}	Cs^{137}	Sr^{89}	Sr^{90}	Sr^{89}/Sr^{90}	Cs^{137}/Sr^{90}	"K"	"K"/Sr^{90}
Iowa City	9833	I-54	4-1-59	50	48/48.5	34	1722														
	9834	I-53	4-8-59	90	91/91.75	8															
	9873	I-55	4-4-59	65	65.5/65.25	8	1752														
Texas	9835	T-329	4-2-59	80	81.5/80.1	8	1784														
	9867	T-331	4-6-59	65	65	8	1427														
	9868	T-338	4-6-59	90	91.8/90.0	8	1748														

APPENDIX D

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU
WASHINGTON

Analysis of Stratospheric Strontium-90 Measurements

L. Machta and R. J. List
U. S. Weather Bureau
March, 1959

Research sponsored by the Division of Biology and Medicine
U. S. Atomic Energy Commission

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I. Introduction

Since it was first proposed by Dr. W. F. Libby[1] in 1953, the concept of stratospheric storage of long-lived fission products resulting from the detonation of high-yield nuclear devices has become generally accepted. As of the end of 1958, Libby[2] has estimated that about 65 megatons of fission products had been injected into the stratosphere. Knowledge of the fate of this debris, which may remain in the stratosphere for a period of years, is vital to our evaluation of the problem of long-lived fission products, such as Strontium-90 and Cesium-137.

The atmospheric processes which control the movement of debris in the stratosphere, its eventual removal into the troposphere and its deposition in the biosphere are determining factors in being able to predict future levels of contamination from debris already in the atmosphere and from debris which may possibly be injected in the future. This understanding will also permit the design of an optimum monitoring and sampling program to keep track of the stratospheric Sr-90. A corollary of the study will be a better understanding of the meteorology of the stratosphere, since these fission products represent one of the few tracers available to study stratospheric motions.

In this paper we should like to review the estimates of what is expected to be found in the stratosphere, the various hypotheses advanced concerning the distribution of radioactivity in the stratosphere and its subsequent removal, and how this fits the observed stratospheric concentrations, along with an estimate of the quality of the data obtained.

II. Estimated Stratospheric Content

It has been customary to divide the radioactive debris resulting from the detonation of nuclear devices into three categories: (1) close-in fallout, (2) tropospheric debris and (3) stratospheric debris. The apportionment in any individual case is a function of the energy of the burst and the conditions of firing (e.g., surface, tower, air, underground, etc.). For bursts

fired at or near the surface of the ground, a large fraction of the fission-product activity is deposited within the first day in the general area of the test site, due to condensation and scavenging by the large particles sucked into the rising fireball. Those particles which are too small to have appreciable fall rates are carried away from the burst site by the winds. For detonations with yields of less than 1 megaton, all of these small particles are left in the troposphere, where they are eventually removed from the air by precipitation scavenging and impaction at the ground. There is general agreement (Libby,[3] Stewart et al,[4] National Academy of Sciences[5] and many others) that the mean lifetime of a particle in the troposphere, before it is removed, is about a month.

Here, however, we are concerned primarily with the effects of very large yield bursts, those powerful enough to inject large quantities of debris into the stratosphere, i.e., yields greater than one megaton, and in particular with the fate of the Sr-90 resulting from these bursts.

Strontium-90 is singled out, of course, because it is thought to represent the principal long-term potential biological hazard from nuclear testing. However, this isotope is also of particular interest in studying stratospheric motions because of apparent very small particle size. It is produced as a daughter product of Krypton-90 as follows:

$$\text{Kr-90} \xrightarrow{33\ \text{sec}} \text{Rb-90} \xrightarrow{2.7\ \text{min}} \text{Sr-90} \xrightarrow{28\ \text{yr}} \text{Y-90} \xrightarrow{64.6\ \text{hr}} \text{Zr-90(stable)}$$

This means that the Sr-90 will tend to condense later than the bulk of the fission products, resulting in the formation of sub-micron particles which are easily carried into the stratosphere by the ascending cloud, and which may have negligible fall rates.

Stratospheric injections of Sr-90, as estimated by Libby,[2] are shown in Table 1. These estimates are based on a series of assumptions and speculations concerning the nature of the fallout. The stratospheric content of Sr-90 is obtained by the subtraction of local and tropospheric fallout from the total Sr-90 radioactivity produced by nuclear explosions whose clouds enter the stratosphere. Local fallout is assumed to be 80 percent for land surface shots, 20 percent for surface water shots and 10 percent for air shots. Shots of more than a megaton yield are assumed to put 1 percent of the debris which did not fall out locally into the troposphere and the remainder into the stratosphere. Shots in the kiloton range are assigned to the troposphere.

There are many uncertainties in these estimates. For example, the 80 percent local fallout from surface bursts is primarily based on very incomplete monitoring data for the Castle Bravo shot, and even if the distribution of total fallout of gross fission products were known, the question of fractionation of the Sr-90 remains unsolved. There is uncertainty concerning the fraction of debris from large shots which remainsin the troposphere, with evidence that it is as much as 5 percent. Another uncertainty is the yield and conditions of firing of the USSR tests. With all these uncertainties, it is obvious that direct sampling is needed to determine the actual Sr-90 content of the stratosphere.

Table 1

Estimated Stratospheric Injections
(after Libby[2])

		MT
1952	Fall	1.0
1954	Spring	19.5
1955	Fall	1.2
1956	Summer	5.5
	Fall	3.0
1957	Spring	3.0
	Fall	4.5
	Fall	1.5
1958	Winter	3.3
	Spring	4.0
	Fall	20.0

III. Other measurements

The reservoir of radioactive debris in the stratosphere has been established by direct measurement, at least in the lower stratosphere, by several investigators prior to the establishment of the AEC balloon sampling program. However, these earlier techniques were confined to total activity measurements rather than to the determination of specific isotopes. In 1954 and early

1955 so much of the debris originated from the Spring 1954 test series (Castle) that one could reasonably assign an origin to the fission products and deal with the gross activity, if fractionation could be neglected. After 1955, the number of tests were so numerous that almost all samples contained fission products from many tests. The method of estimating individual isotopes from the gross fission product activity and burst assignment was no longer as useful.

Aircraft filtering flights reaching into the lower stratosphere have been reported by Stewart et al,[4] by Aler, Bjornerstedt, Edvarson and Low[6] in Sweden, and by Hvinden[7] in Norway. All showed significant increases in the long-lived radioactivity of the air with increasing altitude, and a relatively sharp increase at or near the tropopause. The results are shown in Figure 1.

Ishii[8], in Japan, employed a technique utilizing balloon-borne Geiger counters to attain altitudes of 50,000 feet, compared to the 40,000 feet attained by the aircraft. However, this technique had the drawback of measuring the total gamma activity in situ, and it was necessary to subtract the cosmic ray contribution based on a knowledge of the mean distribution of cosmic-ray activity with altitude. The two contributions were of about the same order of magnitude in the lower stratosphere. While these flights showed higher concentrations of fission products at the tropopause level, they did not show the sharp gradient at the tropopause or the large differences between the troposphere and stratosphere.

IV. Models of Stratospheric Storage and Fallout

Utilizing the estimates of stratospheric injection, the scanty upper-air measurements available and the observations of surface deposition, several estimates of the probable residence time of Sr-90 particles in the stratosphere have been made. Libby[3] estimates about 10 ± 5 years, Stewart et al[4], 5-10 years, Machta[9], about 5 years, and the U.N. Scientific Committee[10] a value of about 8 years with a range of 5-10 years. All of these estimates imply a stratospheric structure at variance with known meteorological principles (this has been recognized by the last two references cited). The concept of an unvarying mean residence time for stratospheric debris would imply uniform mixing in the stratosphere with a semi-permeable membrane at the tropopause and would be independent of the actual altitude

of injection of the debris. Such conditions do not, of course, prevail in the stratosphere.

Proposed models of stratospheric transport and removal have been developed by several investigations to explain the observed Sr-90 patterns at the ground. Three such models will be mentioned here.

The first, due to Dr. Libby, assumes that in the main, debris is uniformly distributed throughout the stratosphere relatively quickly, that a fixed fraction per year of the stratospheric debris enters the troposphere more or less uniformly over the world, and that deposition is principally in precipitation (this last assumption is common to all models). Irregularities in the observed distribution such as the large Sr-90 deposition observed in the north temperate latitudes and apparent changes in the rate of deposition at certain stations are assumed to be the result of tropospheric fallout from kiloton-yield tests in Nevada and the USSR.

Martell has modified this simple model to allow for a difference between the behavior of debris from the large U. S. Pacific shots and the USSR thermonuclear bursts which inject their debris into the polar or temperate latitude stratosphere. It is his contention that the U. S. Pacific bursts contribute to a relatively uniform world-wide stratospheric fallout, while the stratospheric debris from the USSR thermonuclear bursts has a shorter residence time in the stratosphere, of the order of a few months. He concludes that the increased fallout in the north temperate latitudes is due to stratospheric fallout from Russian debris which was injected into the lowest layers of the stratosphere.

Machta and List[12] in this country and Stewart and others in England have developed a model originally proposed by Brewer and Dobson based in part on independent meteorological evidence from water vapor and ozone distribution, which calls for a principal source of stratospheric air in the ascending currents of the tropics, with a slow poleward drift, particularly in the winter hemisphere, and a sink over the temperate and polar regions. This circulation, together with the known precipitation patterns, is used to explain the observed fallout of Sr-90 and the apparent increase in the rate of fallout during the spring season.

Each of these models would predict a somewhat different distribution of Sr-90 in the stratosphere. Dr. Libby's would, of course, call for a uniform

distribution throughout the stratosphere a short time following the injection. The distribution predicted by the other two models would at times have a superficial resemblance, since shortly after a fall or winter Russian series, both would call for increased concentration of Sr-90 in the lower north temperate stratosphere. However, if it were possible to determine the age of the debris, Martell's model would indicate newer debris in this area of high concentration as compared to the other models. The model proposed by Machta and List suggests that the higher concentration would be a persistent feature in the north temperate stratosphere, while Martell would expect this concentration to be a transient phenomenon, appearing only for a period of several months following Russian tests. Both models would predict a shorter stratospheric residence time for Russian debris as compared to debris from the U. S. Pacific tests.

The limited amount of actual observational data from the stratosphere makes it necessary that some model of the stratospheric distribution be constructed if any effective use is to be made of the data in predicting future fallout. As yet, there is not enough direct observational data from the stratosphere to conclusively suggest one model over another and it may be that all of the models discussed are grossly in error.

V. Stratospheric Balloon Data

Since the end of 1956, the Atomic Energy Commission has been conducting a program, Project Ashcan, to measure the radioactive dust content of the stratosphere by means of balloon-borne filters. The program calls for monthly collections at each of four stations, Minneapolis, Minnesota, San Angelo, Texas, Panama and Sao Paulo, Brazil, at four altitudes: 50,000, 65,000, 80,000 and 90,000 feet. The filters are recovered and analyzed for gross beta activity and for six specific radioisotopes, Ba-140, Zr-95, Ce-144, Cs-137, Sr-89 and Sr-90. Of primary concern are the relatively long-lived isotopes, Sr-90 and Cs-137, since these are believed to represent the principal possible long-term hazard resulting from nuclear testing. The measurement of shorter-lived isotopes contributes to the understanding of the origins and movement of stratospheric debris.

Figures 2-5 show the Sr-90 data in disintegrations per minute per 1000 standard cubic feet at the four stations as a function of altitude and time and uncorrected for filter efficiency. Vertical lines indicate the depth of

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the atmosphere sampled on the several flights which sampled through appreciable vertical thickness. A few flights made in Arizona are shown on the Texas figure in italics. The arrows at the top of Fig. 2 (Minneapolis) indicate the dates of the large Russian nuclear detonations which presumably injected debris into the temperate or polar stratosphere. Similarly, the arrows at the top of Fig. 4 (Panama) indicate the megaton range devices detonated by the United States and the United Kingdom in tropical latitudes.

An inspection of the data shows that there is a large variability. This variability may be real, and a measure of the true state of affairs in the stratosphere, or it may be a function of the collection or analysis techniques. Some of the variability must be a reflection of recent injections into the stratosphere. For example, the high values over Minneapolis in late April and May of 1957 may be a result of the April Russian thermonuclear tests, similarly the high value over South America in July, 1957, may reflect injections from the U. K. tests of the preceding month.

A major difficulty in making a quantitative estimate of the Sr-90 content of the stratosphere results from the lack of precise knowledge of the efficiency of the filter material at the low pressures and flow rates encountered, together with a lack of knowledge of the particle sizes involved. Although theoretical and laboratory studies on the characteristics of the filter system have yielded information for particles as small as 0.088 μ, a comparison of collections made by aircraft at 40,000 feet simultaneously with balloon collections indicate that the collection efficiency curves must be extrapolated to 0.02μ or smaller particles to explain the Sr-90 values. Using this semi-empirical approach, a series of filter efficiency factors for Sr-90 particles of 0.02μ were obtained (Table 2).

Table 2

Filter efficiency for 0.02μ particles

Altitude, feet, MSL	Filter Efficiency
50,000	0.30
65,000	0.38
80,000	0.60
90,000	0.82

The sparsity of stations and the variability of the data make it impracticable to draw an instantaneous picture of the world-wide distribution of Sr-90. However, it is possible to make a rough estimate of the average concentration and distribution of debris in the stratosphere over an extended period of the order of six months. Figure 6 shows the average concentration of debris in the stratosphere as a function of altitude and latitude for two six-month periods, January - June, 1957, and January-June, 1958. The data at each sampling altitude and station were averaged over the period and corrected for the filter efficiencies given in Table 2.

It is evident that the sixteen data points, each based on a mean of only a few observations with large variability cannot serve to define the stratospheric Sr-90 content of the world. However, some information as to the distribution can be extracted. A series of isolines showing what is felt to be the most probable distribution based on the available observations are also shown, although there are admittedly many other logical patterns which may be drawn.

A comparison of the two cross-sections shows that between the first half of 1957 and the first half of 1958, there appeared to be a general decrease in the intensity of the gradients observed, principally due to a decrease in the concentration of Sr-90 at the two northernmost stations at 65,000 feet. Another evident change is the increase at all levels over the Canal Zone, possibly as a result of the British thermonuclear tests in the Christmas Island area which occurred in May, June, and November of 1957. These tests may also be responsible for the increases at 90,000 feet over Texas and Minnesota.

The patterns shown in Figure 6 may be integrated to estimate the total stratospheric burden of Sr-90. This computation gives the equivalent of 7.8 MT of fission products in 1957 and 5.5 MT in 1958. (A computation based on 0.25 filter efficiency factor at all altitudes gives 12 MT in 1957 and 8 MT in 1958). These figures can be compared with estimates of the stratospheric content made by budgeting the debris. Table 1 shows that about 39 MT had been injected into the stratosphere as of the end of 1957. However, much of this debris has been removed from the stratosphere. Libby estimates the mean removal rate to be about 10% per year, Machta and List about 20% per year. These estimates would result in a stratospheric content of 20 to 24 MT

in early 1957 and 26 to 34 MT in early 1958. In either case, it is apparent that the uncertain estimate of the stratospheric content from the balloon data is appreciably smaller than that estimated from the budgeting of bomb releases and the change from 1957 to 1958 is in the opposite direction.

The discrepancy in the two calculations of the stratospheric Sr-90 content can result from a variety of causes. The uncertainties of the estimate based on the amount injected have been discussed. An equal or possibly larger uncertainty exists in the estimate derived from the balloon measurements. Among the problems are:

A. The representativeness of the limited number of measurements.

B. Knowledge of the actual amount of air filtered on any given flight.

C. Efficiency of the filter for the particle sizes involved.

D. Radiochemical analysis.

A. Representativeness of the data. If the high atmosphere is indeed as variable as the stratospheric balloon flights indicate, then the few samples, one flight a month at a total of 16 places in the atmosphere (4 stations at 4 altitudes), cannot be considered adequate to define the world-wide stratospheric content with the desired accuracy. Although there is no conclusive evidence to preclude the possibility that this variability is real, a consideration of diffusion rates suggests that the fission products are not as patchy as the balloon data indicate.

B. Volume of air filtered. The question of the reliability of the fan law used in calculating the volume of air passing through the filter is under investigation by General Mills. In an attempt to see if there is an obvious bias in the results from this cause, the Sr-90 content of the samples was plotted against the reported volume at the various stations and altitudes. If a consistent error in the fan law were present, this would appear as a relationship between the apparent volume of air filtered and the reported air concentration. No such relationship was found. This, of course,does not rule out the possibility of other non-systematic errors in the determination of the volume filtered.

C. Filter efficiency. Many studies have already been made on the problem of the efficiency of air filters for small particles, but the basic problem - the size of the particles with which we are dealing - has not been solved. The extrapolation of laboratory determinations of collection efficiency based on

larger particles, to particles as small as 0.02μ is certainly unreliable, as is the use of the airplane comparison in indirectly determining the particle size. Also adding to the uncertainty in the filter efficiency problem, is the question of flow-rate. It has been assumed that a linear velocity of 100 feet per minute prevails at all times and altitudes. It may perhaps be necessary to determine the flow rate for individual collections, again based on the fan law, once the particle size and efficiency curves are established. Such refinement is probably not warranted at present.

D. Radiochemical Analysis. The stratospheric filters are routinely analyzed for the following fission products:

Table 3

Isotopes Analyzed

Isotope	Half-life
Ba-140	12.8 days
Zr-95	65 days
Ce-144	275 days
Cs-137	28.8 years
Sr-89	50.5 days
Sr-90	27.7 years

Sr-90 is, of course, the isotope of principal concern in evaluating the long-term hazard of delayed fallout. Cs-137, with a similar half-life, fission yield and mode of formation serves as a check on the data and is also of interest as a long-term fallout hazard.

Information on the observed Cs-137/Sr-90 ratio in fallout is available from other sources and can be compared with the balloon filter results. Baus et al[13] of the Naval Research Laboratory have determined the ratio in air filtered at the ground at a series of stations along the 80°W meridian extending from Thule, Greenland, to Punta Arenas, Chile, using monthly collections. Stewart et al[14] in England have made measurements using a world-wide precipitation network making monthly collections. Storebø[15] in Norway, used Stewart's data, together with some additional measurements in Norway, to conclude that there is a difference in behavior of the two isotopes, and suggests that the Sr-90 is more easily captured by rain. If this is a result of some physical parameter, like particle size, a systematic distribution of the Cs-137/Sr-90 ratio with altitude should be seen in the balloon data.

Figure 7 shows the balloon Cs-137/Sr-90 data as a function of altitude. Only those samples with more Sr-90 than 10 dpm per 1000 scf were used to avoid spurious values. The several laboratories involved in the radiochemical analysis program are differentiated by symbols. The results show that there is a tendency for the ratio to increase with altitude, although the variability is large. The data are summarized in Table 4, together with the data from the other investigators. (Certain doubtful values have been excluded in the U.K. rainfall results.)

Table 4

Summary of Cs-137/Sr-90 Data

	No. Cases	Mean	Standard Deviation
Balloon filters:			
50,000 feet	13	2.11	1.11
65,000 feet	48	2.80	1.31
80,000 feet	26	3.42	1.45
90,000 feet	15	3.53	1.99
NRL surface air filters	59	2.20	0.73
U. K. rainfall	122	1.63	0.63

As can be seen from the last column of Table 4, the standard deviation of the Cs-137/Sr-90 ratio from the balloon filters is two to three times greater than found by other investigators. This may be a result of radiochemical procedures and is undoubtedly a function of the extremely minute amounts of material collected during the flights.

The relatively short-lived isotopes, Ba-140, Zr-95 and Sr-89, can reveal information on the age and origin of the activity sampled, particularly if the debris is fresh, but the great variability found in these isotopes has made interpretation difficult. This variability may be real, reflecting the patchy nature of fresh debris.

Cerium-144 tended to show more meaningful patterns than the shorter-lived isotopes. It has a half-life of 275 days (0.75 yr) and a fission yield about 25% greater than that of Sr-90. If it can be assumed that fractionation is unimportant and the collection efficiency of the filter for the two isotopes is about equal, the Ce-144/Sr-90 ratio can be useful in distinguishing between sources of debris of different ages. In the first half of 1957, the ratio for Castle debris should be about 3 or 4, while Redwing debris would have a value

of about 25. For very fresh debris, less than 2 months old, the ratio would be over 40. The proviso concerning fractionation and collection efficiency is an important one, since unlike Sr-90, Ce-144 has no gaseous or volatile precursor, which may indicate that larger particle sizes are involved having greater fall rates. These larger particles, if present, may also be more readily captured by the filter. Absolute values of the ratio may be meaningless, but relative values may be useful in comparing ages of debris at the same altitude.

Figures 8-11 show the Ce-144/Sr-90 ratio (large figures) superimposed on the Sr-90 data. As with the other balloon filter results, there appear to be random fluctuations in the data. However, some patterns can be seen. For example, increases in the Ce-144/Sr-90 ratio at 50,000 feet over Minneapolis and at 50,000 and 65,000 feet over Texas in late 1957 and early 1958 could be the result of Russian injection during the autumn of 1957. In general, the values at 65,000 feet over the two northern stations indicate much younger debris (higher Ce-144/Sr-90 ratio) than over Brazil at the same altitude. At Brazil, increases in the ratio can be seen as a result of the British tests in the spring of 1957 and of the U. S. Pacific test series in 1958.

The foregoing discussion of the radiochemical data would seem to indicate that some qualitative reliance may be placed on the results, but that the variability seems to be larger than expected and may partially be a result of analysis procedures. The very minute quantities of debris captured by the sampling equipment make the radiochemical procedures extremely difficult.

VI. Conclusions

In evaluating the possible hazard from Sr-90 and other long-lived fission products, it has been established that stratospheric storage plays an important role. It then becomes necessary to know the content, distribution and rate of removal of debris from the stratosphere. Indirect determinations of the content, based on assumed initial injections, are too uncertain and meteorological knowledge of stratospheric motions is too poor to satisfy questions on these subjects. We must rely on direct measurement of the stratosphere.

It is evident that there are many uncertainties in the data collected in stratospheric sampling programs, but that a potential exists for a valuable contribution, by good sampling and analysis, both to the Sr-90 problem

and to the meteorological problem of stratospheric transport, diffusion and removal. The basic problems of particle size and filter efficiency have to be solved. It may be that an indirect method, such as comparison with aircraft or whole air collection, will be the only way to provide a solution to the calibration of the balloon sampling. In that event, a number of comparisons at various altitudes will be necessary to establish this calibration. It will also be necessary to perform these comparisons for each of the isotopes of interest.

If the mechanical problems related to the collection of debris can be solved, the question of the quality of the radiochemical analyses becomes even more important. The large unexplained fluctuations in the ratios of the various isotopes suggests that much of the variability arises from this source. If it turns out that the variations observed in the past data are indeed real, then the four-station network sampling each altitude once a month now in existence would be inadequate. However, information presently available concerning the stratosphere suggests that the variations are improbable, especially when viewed in light of the estimate that most of the debris injected into the stratosphere before 1958, came from the Castle series in the Spring of 1954, three to four years prior to the measurements disuussed here.

It is also possible that the relatively low stratospheric content indicated by the balloon data, and the decrease between 1957 and 1958, represents the best estimate, and that the models of injection and stratospheric-troposphere exchange that have been employed are grossly in error. This would imply a much faster exchange than has been postulated or smaller initial injections or both.

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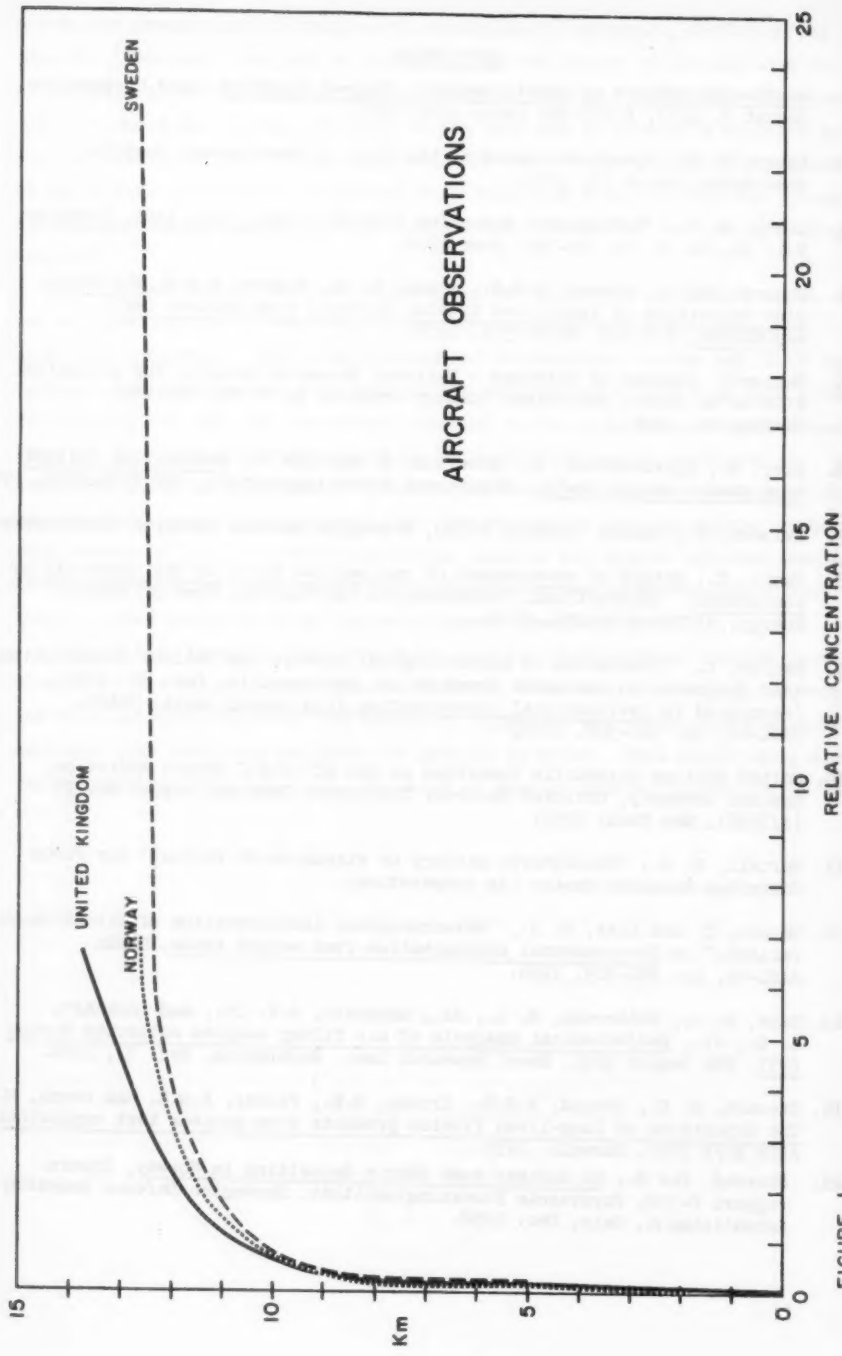
AIRCRAFT OBSERVATIONS
SWEDEN
NORWAY
UNITED KINGDOM
Km
15
10
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20
25
RELATIVE CONCENTRATION

FIGURE 1

FIGURE 1 RELATIVE CONCENTRATION

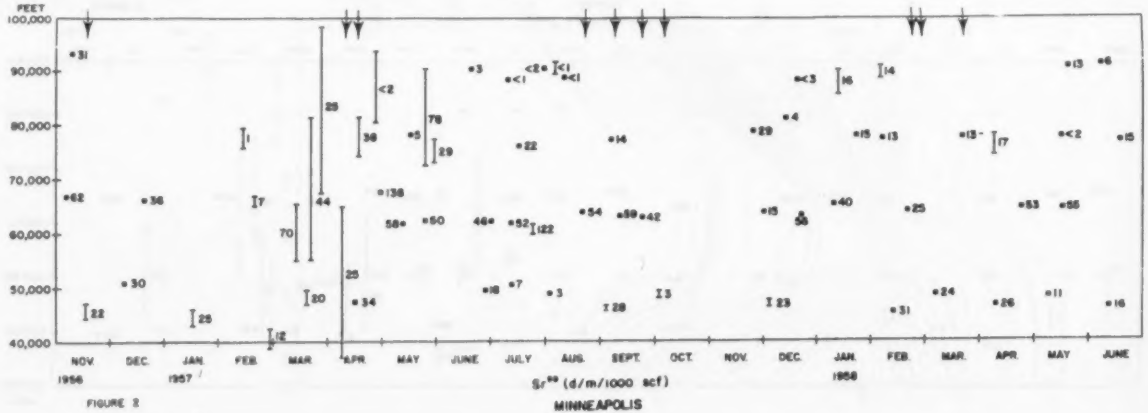
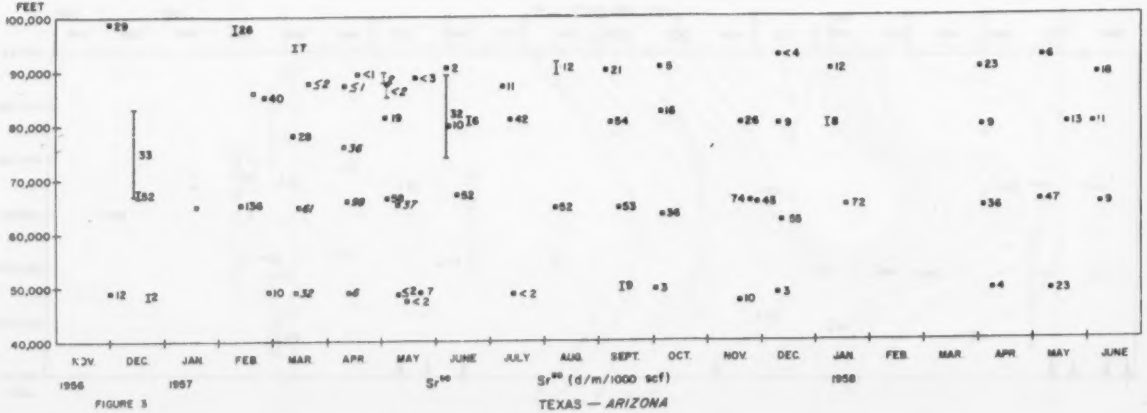


FIGURE 2



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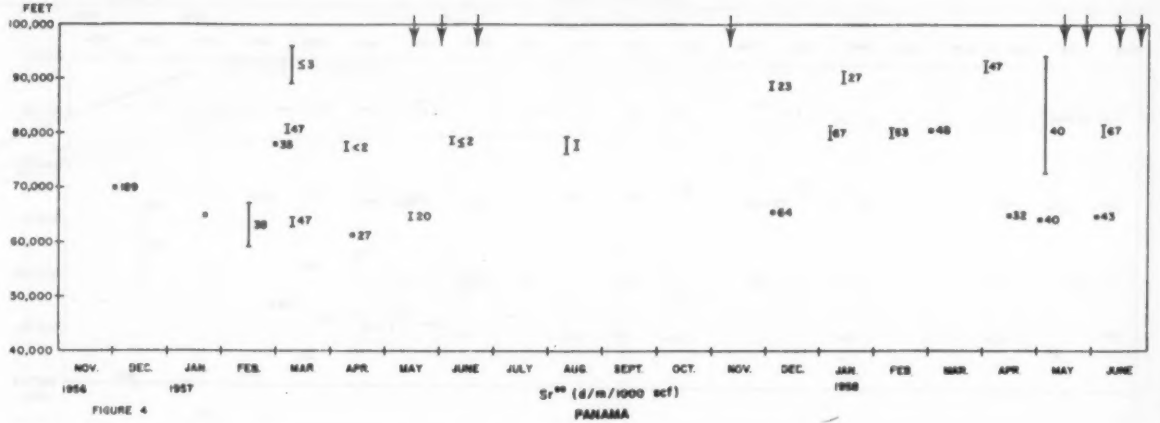
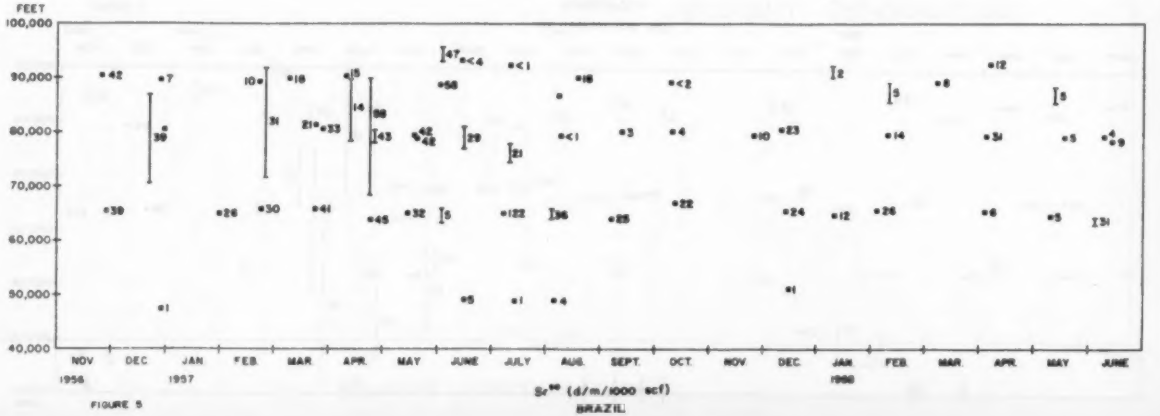


FIGURE 4



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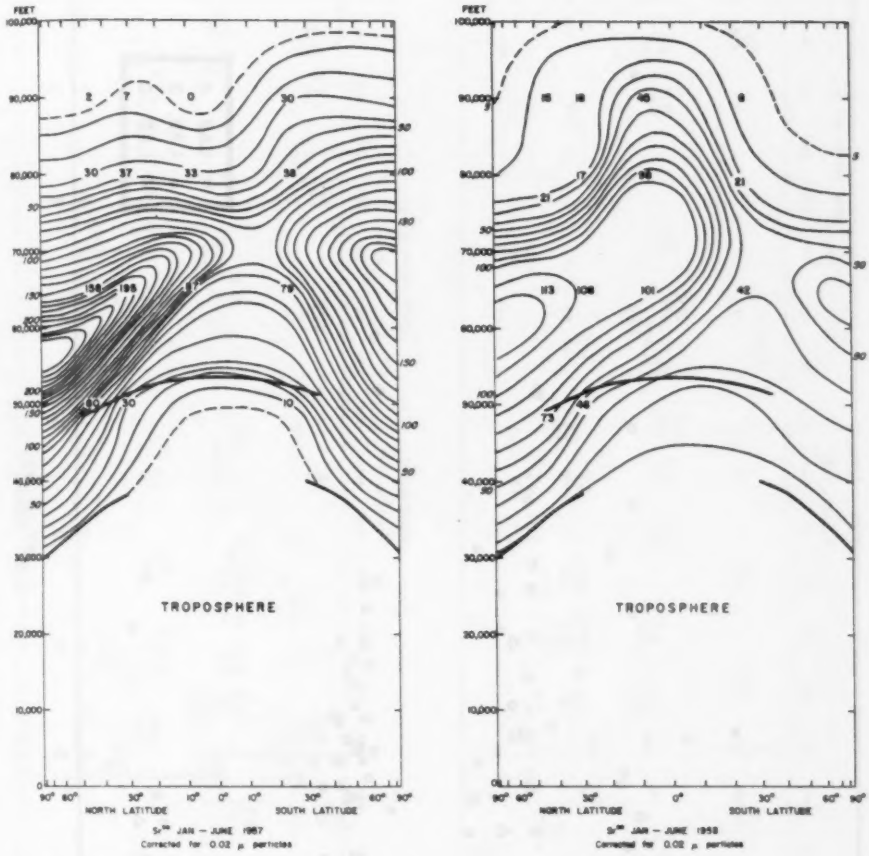
FEET
TROPOSPHERE
NORTH LATITUDE
SOUTH LATITUDE
TROPOSPHERE
NORTH LATITUDE
SOUTH LATITUDE

FIGURE 6

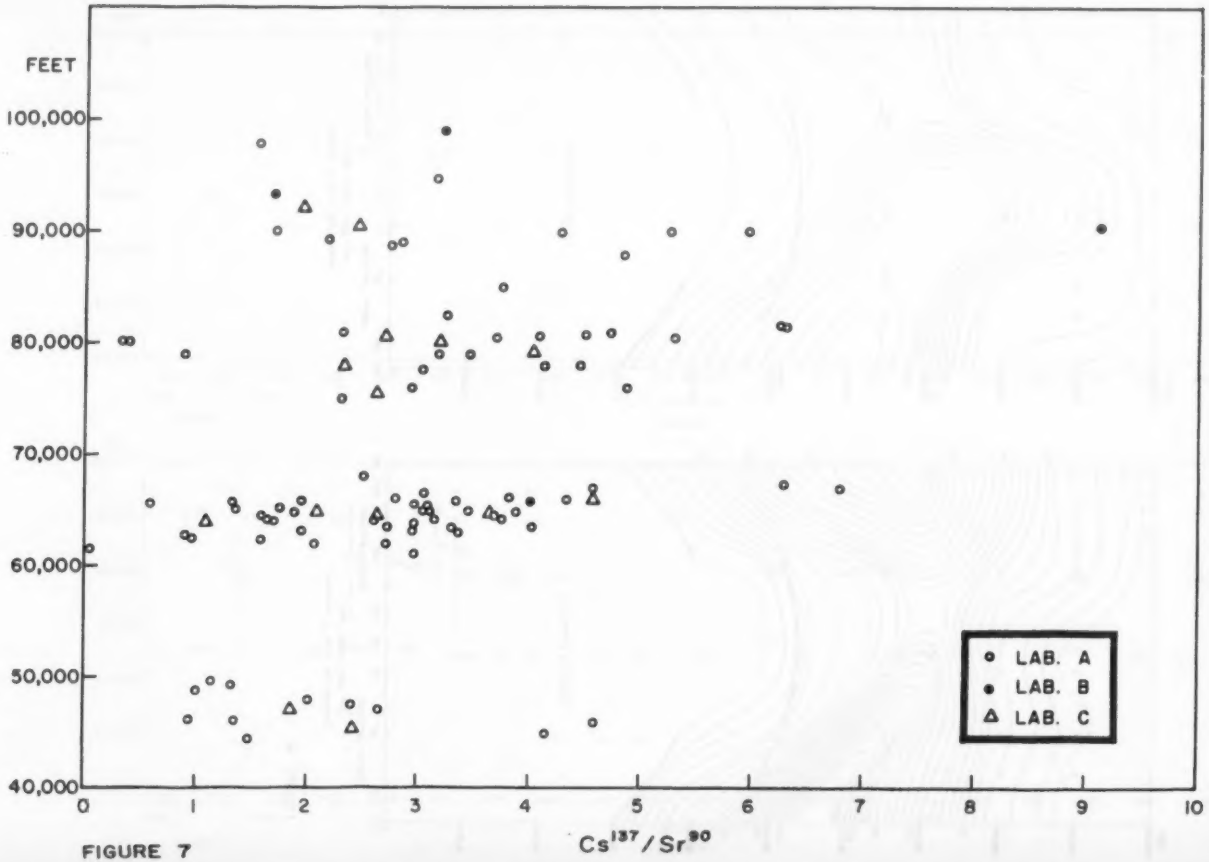
FEET
100,000
90,000
80,000
70,000
60,000
50,000
40,000
0
1
2
3
4
5
6
7
8
9
10
LAB. A
LAB. B
LAB. C
Cs137/Sr90

FIGURE 7

FEET
100,000

FIGURE 7 Cs^{137}/Sr^{90}

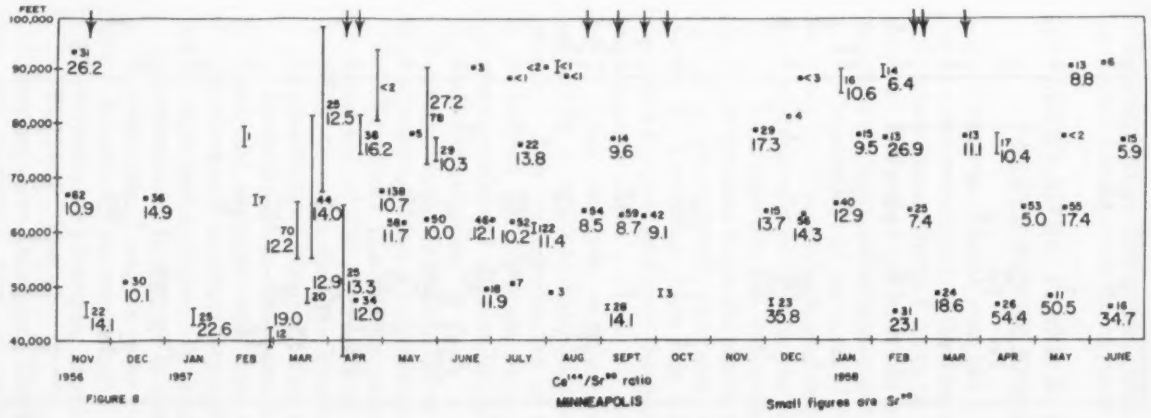

FIGURE 8

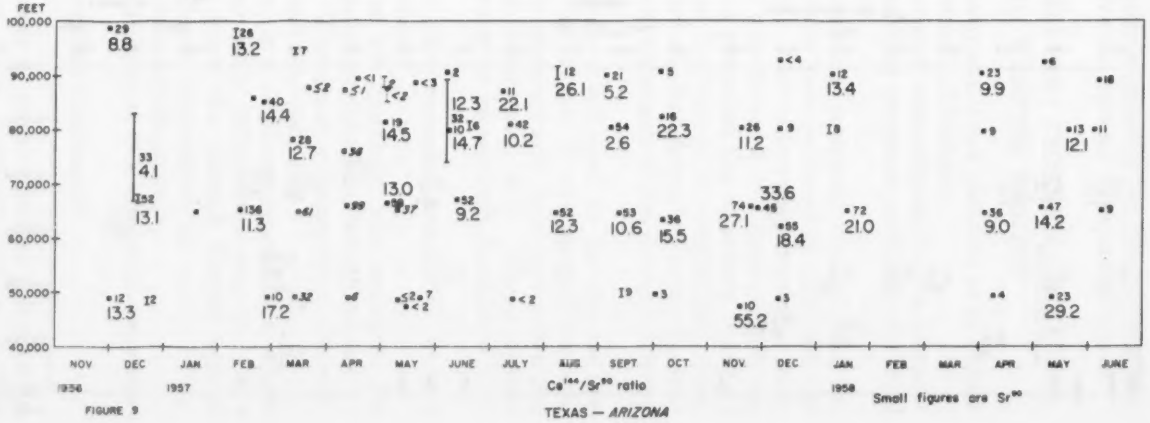

FIGURE 9

FIGURE 10

FIGURE 11

Representative HOLIFIELD. Our next witness is Dr. Frank Shelton, Technical Director of the Armed Forces Special Weapons Project.

STATEMENT OF DR. FRANK H. SHELTON,[1] TECHNICAL DIRECTOR, ARMED FORCES SPECIAL WEAPONS PROJECT

Dr. SHELTON. Thank you, Mr. Chairman, it is a pleasure to be before you as a representative of the Department of Defense.

The new data which I have to present were obtained by a Department of Defense high altitude sampling program utilizing aircraft to obtain the fission debris samples.

The feasibility of an aircraft sampling program was studied extensively in 1955, budgets and contracts were initiated in 1956 and the high altitude sampling program that I am discussing began in mid-1957. To single out the individual who foresaw the basic soundness, the superior data to be obtained, and provided the necessary spark of initiating the aircraft program, that individual is clearly Maj. Gen. Alvin A. Luedecke, then the Chief of the Armed Forces Special Weapons Project and now the general manager of the Atomic Energy Commission.

The high altitude sample program (referred to by its initials as HASP) is under the direction of the Armed Forces special weapons project. The radiochemistry of the samples and data interpretation is performed by Isotopes, Inc., of Westwood, N.J. The program utilizes a number of unarmed single engine jet aircraft, Lockheed U–2, to obtain the samples.

Representative DURHAM. How is that contract handled? Is it a contract through the Air Force or whom?

Dr. SHELTON. We have a number of contracts, the contracts for procurement of the aircraft and their modification was financed by AFSWP through the Air Force. These are military-type aircraft.

Representative DURHAM. You mean Isotopes, Inc.?

Dr. SHELTON. No. Isotopes, Inc., is a civilian organization which analyzes our samples and does our data interpretations, that is a straightforward contract straight from the Armed Forces special weapons project to them. We handle our own contracts.

Representative DURHAM. Is that a nonprofit outfit?

Dr. SHELTON. I am not sure I could say it is a nonprofit organization. It is a civilian contractor.

Representative DURHAM. It is a civilian contractor?

Dr. SHELTON. Yes, sir.

Representative DURHAM. Then most of your technical information you are receiving you are getting from contract service, is that correct?

Dr. SHELTON. That is correct. Normally an organization such as AFSWP would not maintain a radiochemistry facility. We would go to the private industry to find that facility and that is the situation in this case. We contract out most of our work, that is correct.

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[1] Technical director of the Defense Atomic Support Agency. He has been active in the atomic energy field since 1952. During the spring of 1955, he served as technical adviser to the military effects test group at Operation Teapot, and in 1953 participated in Upshot-Knothole. Dr. Shelton was born in 1924. He received his bachelor of science, master's, and doctor of philosophy degrees, all in physics, from the California Institute of Technology. Prior to joining the Defense Atomic Support Agency, Dr. Shelton was with the Sandia Corp. in the weapons-effects field.

Representative DURHAM. How much are you spending in your contract?

Dr. SHELTON. Let me refer just to this program. Our fiscal budget on the HASP program is running about a million dollars a year. It has been higher in the past when we were modifying the aircraft. I am referring to a program that has been underway for a number of years. I think it represents about a total of about $5 million now.

Representative DURHAM. Who was that authorized by? Was it authorized by the Armed Services Commitee? How did you get authorization?

Dr. SHELTON. Normally the budget for AFSWP, as you may know, is taken first to the House Military Appropriations Subcommittee and then passes from there to the Senate Appropriations Committee. The normal budgeting of the AFSWP is done by AFSWP before the committees.

Representative DURHAM. It doesn't appear as a line item in your appropriation?

Dr. SHELTON. It is usually discussed, that is correct. The whole AFSWP budget occurs as one item.

Representative DURHAM. Do you classify research and development funds?

Dr. SHELTON. We do not classify the individual costs, no. It is not a classified cost.

Representative HOLIFIELD. You may proceed.

Dr. SHELTON. After an initial crew training and test period, the sampling aircraft were based in New York State and Puerto Rico. From these two bases a north-south sampling corridor (along the 70° west meridan, east coast of the United States) and extending from 66° north to 6° south latitude was monitored systematically from November 1957 through May 1958.

Since about mid-1958 the aircraft have operated from Puerto Rico and Ezeiza Airport near Buenos Aires, Argentina, in order to sample the Southern Hemisphere. We have monitored the Southern Hemisphere to about 57° south latitude, and periodically remeasured the Northern Hemisphere. Concerning the other operational aspects of the sampling program and the accompanying laboratory and experimental programs, I would like to submit for the record my previously prepared and circulated text and now pass to a brief description of the results and conclusions.

Representative HOLIFIELD. It will be received.

(The material referred to appears on p. 772.)

Dr. SHELTON. While the results were obtained principally from the Armed Forces special weapons project's HASP program, some use has been made of other Department of Defense aircraft sampling programs and some use has been made of the results of the Atomic Energy Commission balloon Ashcan program to extend the results to high altitude.

With respect to the results, there are four basic topics and they are:

1. First: Are the long-lived fission products uniformly distributed in the stratosphere? That is, does the Southern Hemisphere and Northern Hemisphere have the same stratospheric burden of fission products? The answer is "No." The HASP results conclusively and clearly show that there is a much larger stratospheric burden of fis-

sion products in the Northern Hemisphere than in the Southern Hemisphere. In mid-1958, prior to the extensive U.S.S.R. series in the fall of 1958, the HASP program obtained about 0.8 megacuries of Sr^{90} in the stratosphere of the Northern Hemisphere and now we estimate from measurements that about one-half that amount existed in the Southern Hemisphere—about 0.4 megacuries. That is; there was twice as much stratospheric fission debris in the Northern Hemisphere as the Southern Hemisphere, and after the U.S.S.R. fall 1958 series the disparity is even larger.

The total 1.2 megacuries in the stratosphere in mid-1958 corresponds to about 12 megaton fission yield of Sr^{90}. I would estimate the uncertainty in that value as less than 25 percent.

Why are the hemispheres unequal? The answer is clear from the aircraft data (and I suspect the ground data show the same thing).

(a) The U.S.S.R. fission debris is introduced into the stratosphere at high northern latitudes and does not spread across the Equator to the Southern Hemisphere at a rate comparable to the rate at which it is deposited on the ground in the Northern Hemisphere.

(b) A second reason for the nonuniformity in the hemispheres concerns the United States large-yield shots at the Eniwetok Proving Grounds—which is about 10° north latitude—the fission debris in the stratosphere spreads preferentially into the Northern Hemisphere. This uneven spread is easily verified by monitoring the tungsten I^{85} of Operation Hardtack in the stratosphere or on the ground.

The results clearly show that the average for many U.S. shots which contained tungsten a preference for spreading to the Northern Hemisphere and is thus indicative of the spread of fission debris.

The conclusion is: That as a result of nuclear testing to date, the concentration of Sr^{90} and other long-lived isotopes will be larger on the ground in the Northern Hemisphere than the Southern Hemisphere. The often proposed assumption that the stratosphere is uniform north to south is clearly incorrect as well as the conclusions so drawn.

2. The second topic of HASP results is related to the uniformity of fission debris in the stratosphere with respect to altitude and concentration of air. That is; is the stratospheric reservoir of fission products uniform with respect to the air concentration? The answer is "No." The HASP aircraft program, with the AEC balloon data, shows that the maximum concentration of fission products with respect to air (such as disintegrations of Sr^{90} per standard cubic feet of air) occurs near the base of the stratosphere and the concentration decreases with increasing altitude.

The rate of decrease in concentration with altitude is less pronounced in the region of the equator than at the high north or south latitudes. There has often been the assumption that the fission debris was uniform in the stratosphere with respect to the air. This assumption is incorrect and has led to an overestimate of the stratospheric content of fission debris. In summary, the fission products in the stratosphere are not uniform with respect to latitude nor with respect to the air concentration.

3. The third topic of results has to do with the amount of fission debris in the stratosphere when account is taken of the nonuniform-

ity of the distribution. In about mid-1958 the HASP inventory calculations resulted in about 12 megatons fission yield of Sr^{90} in the stratosphere at that time. There were a few U.S. shots after mid-1958 and the extensive U.S.S.R. fall 1958 series of nuclear detonations resulted in the stratosphere reservoir of Sr^{90} rising to its largest content ever and that was about 30 megatons of fission product Sr^{90} in late 1958.

If there is no nuclear testing in 1959, I would expect the stratospheric reservoir to contain about 18 megatons fission yield of Sr^{90} in January 1960. Concerning a material balance; in mid-1958 there were about 12 megatons fission yield of Sr^{90} in the stratosphere and about 30 megatons fission yield of Sr^{90} already deposited on the surface of the earth as a result of worldwide fallout. If all the remaining stratospheric content is deposited on the ground in the same way as in the past, the total accumulated levels on the ground can be expected to about double, which brings me to the fourth and last topic of the HASP result; that is:

4. The average rate of worldwide fallout or the half residence time of the fission debris in the stratosphere. It became abundantly clear last year—during the spring of 1958—that the fission debris from U.S.S.R. shots was being deposited on the ground at a rate very fast compared to the then currently accepted value of 7 years half residence time for worldwide fallout.

The HASP aircraft program monitored the fall 1957 and late winter 1958 U.S.S.R. detonations and we observed their mixing in the polar stratosphere and their spread through the breaks in the tropopauses that occurs at about 40° north latitude. I am sure that the extensive fall 1958 U.S.S.R. series is being deposited this spring in a similar manner and at about the same rapid rate as we observed last year.

The HASP estimate of the half residence time for U.S.S.R. fission debris introduced into the stratosphere at high northern latitudes is about 1 year or less.

In a similar manner using the measured stratospheric inventory and the computed total amount injected by the shots that produced that inventory, the half residence time for United States and Great Britain large yield shots detonated near the Equator is about 2 years or less.

The exact number for the average half residence time is not very important once it is established as being as short as several years, since this must be compared to the half life of Sr^{90} which is 28 years. Essentially, all that goes up, comes down, rather quickly. What is really important is the way it comes down.

The stratospheric fission debris comes down principally through the breaks in the tropopauses, about 40° north or south latitude and causes a concentrated band on the ground in the north or south temperate latitudes according to the amount of rainfall. The nonuniformity on the ground is an important consequence of the differences in the Northern and Southern Hemispheres stratospheric content and the mode of fallout occurring through the region of the tropopause breaks; that is, the worldwide fallout is banded, concentrated on the ground in the regions around 40° north or south latitude with much higher concentrations in the northern region.

A final word: we know the physical data quite well. I propose that we know the physical data so much better than its biological effects, that any small changes caused by refinement of small difference in various organization results just cannot make much difference when compared to what does it mean biologically.

In mid-1958, the HASP program obtained 0.8 megacuries of strontium 90 in the stratosphere of the Northern Hemisphere, and we estimate from the measurements we have taken now from the Southern Hemisphere that there were about 0.4 megacuries of strontium 90. That is, there was twice as much fission debris in the Northern Hemisphere as in the Southern Hemisphere and the total is about 1.2 megacuries which corresponds to like 10 or 12 tons megatons of fission products in the middle of 1958.

Representative HOLIFIELD. In the event of a nuclear war the significance of this would be that most of the weapons would be exploded in the Temperate Zone and therefore most of the fission products would remain in the Temperate Zone?

Dr. SHELTON. I think that is completely a true statement. The weapons that have made this main contribution that I am referring to, which was prior to the fall Russian series, have been some Russian testing, but dominantly U.S. and British testing. Even U.S. testing, as I will show you, does spread preferentially to the Northern Hemisphere also.

Representative HOLIFIELD. Does it also happen that bomb tests in the Arctic zone also are deposited in the Temperate Zone because of the peculiarities that were explained this morning in the tropopause?

Dr. SHELTON. Yes, sir. Why are the hemispheres unequal? The answer for U.S.S.R. Arctic shots is fairly clear from our aircraft data. The U.S.S.R. shots have fission debris which is introduced in the stratosphere at the high northern latitudes and does not spread across the Equator to the Southern Hemisphere at any rate comparable to the rate at which it drops out of the ground or comes out of the stratosphere.

Representative DURHAM. What percentage of your program is classified and what percentage can be made available to the public? You are just adding the results up here.

Dr. SHELTON. As you see, they are gross results. Nearly all of the important results of a program of sampling, such as the AEC balloon sampling program, can be made available. It turns out that the HASP program has been studied shot by shot.

In other words our program has studied shot-by-shot U.S. tests. Nearly the same statement can be made about the British tests, and we have watched Russian series. We have reported in a classified way. We have found that there is an extremely large amount of material in the unclassified literature and very little, if any, reporting in the classified literature of this type of sampling program. We have tried to fill something of a vacuum.

Representative DURHAM. When did you discover that? It has not been so long since it was all entirely classified. The reason I am raising these questions is that we are all in this thing in one way or another. We now have a lot of agencies in this work and I am concerned about the coordination we are getting with the money they are spending. After all, this is taxpayers' money, and I think we are

getting a lot of duplication and we don't get the information from one agency to another where they can be used?

Dr. SHELTON. We have only issued one large report. The report was classified. Let me give you the individuals. We circulated the report widely in the AEC. Dr. Libby has copies. We sent it to Dr. Machta, who is appearing before you from the Weather Bureau. Our reports go to Dr. Martell, who is appearing before you, and to other members of the Department of Defense.

Representative DURHAM. That is a standard procedure and policy at the present time, is that correct?

Dr. SHELTON. On the classified reports which contain the secret restricted data from the U.S. shots and secret data on foreign shots, that is the correct procedure. We and the AEC are declassifying some information. It is a matter of time, of course. I have before me some unclassified data. The Isotopes, Inc., has submitted a report to us for the unclassified literature.

Representative DURHAM. I realize some of it is essential for national security. This field is being pretty fully explored at the present time by scientists throughout the country. What kind of a staff do you have at the present time?

Dr. SHELTON. The AFSWP organization has its headquarters in the Washington area and we have about 250 people. Our main body of people is in Albuquerque in the field command. I think that would run in excess of a thousand, perhaps.

Representative DURHAM. You require technical personnel, physicists and chemists or something like that?

Dr. SHELTON. Yes.

Representative DURHAM. You don't put an ordinary individual in this work?

Dr. SHELTON. That is correct. Most of the technical portions of our program, as I said, are contracted out to competent technical people that can be found in the industrial source.

Representative DURHAM. I read your report—the first and only one you issued.

Thank you, Mr. Chairman.

Representative HOLIFIELD. Dr. Shelton, most of this material that you are giving today was contained with a covering letter from General Loper to Senator Anderson?

Doctor SHELTON. Yes, sir.

Representative HOLIFIELD. You are no doubt aware of the fact that Senator Anderson questioned General Loper quite closely on this matter?

Dr. SHELTON. Yes, sir.

Representative HOLIFIELD. He did so because there was a section in his letter of March 18 which said that "Therefore, we believe, until the results are more than preliminary, the confidential classification should remain on the letter." Has the Department of Defense taken action since that time to make all of this unclassified?

Dr. SHELTON. We have not taken action at the present time to make it all unclassified. There are very legitimate and very straightforward classificattion matters contained in some of our reports and some of the letters exchange to you. The program I am referring to you does have other classified aspects to it. We do utilize other

Department of Defense programs and facilities which are classified. That is what General Loper was referring to.

Mr. RAMEY. I think this letter referred to the results relating to your measurements which are now being classified?

Dr. SHELTON. They are being given to you in a form that is unclassified; that is correct.

Mr. RAMEY. So that you have arrived at the stage now that they are more than being a preliminary and that you have coordinated them with the Atomic Energy Commission?

Dr. SHELTON. The statements that I gave you were coordinated with the AEC prior to them being sent to you. We coordinated our position prior to that time. Again I must say that we coordinated the statements I have to make to you with the classification officer of the AEC. The statements on total yields that you received today, for instance, were until recently classified. Whether we could release those, which are contained in this testimony, was a matter which we had to regard very carefully.

Representative HOLIFIELD. Do you wish to cover the ABCD points?

Dr. SHELTON. I am covering in broad summary the four basic large results of our program. The first one that I had referred to had to do with—are the two hemispheres different, is there a uniformity? I have said it is not uniform in the two hemispheres and that the results at the top of page 9 of my text had a disparity of a factor of two in mid-1958.

The reasons for the disparity is: First, the Russian debris is interjected in the northern latitudes. There had been Russian debris injected in the stratosphere in late 1957 and early 1958, prior to this documentation in mid-1958. The second reason for the nonuniformity in the hemisphere concerns the U.S. shots at the Eniwetok Proving Grounds.

Those proving grounds, as we saw, are about 10° north latitude. The fission debris in the stratosphere from these tests spreads preferentially to the Northern Hemisphere. The uneven spread is easily verified by monitoring the tungsten 185 that we have heard from the previous speaker. The tungsten 185 has spread unevenly in the stratosphere and I think you will find it is uneven on the ground in the two hemispheres at the present time. The conclusion is that as a result of nuclear testing to date the concentration of strontium 90 and other long-lived isotopes will be larger on the ground in the Northern Hemisphere than the Southern Hemisphere.

Those proposals and assumptions of uniformity are incorrect and the conclusion is drawn from the statements of uniformity and probably quite incorrect.

The second large topic of the HASP results relates to one other factor of uniformity and that is altitude of air concentration. Is the stratospheric reservoir uniform with respect to altitude and air concentration, are there the same number of fission products per amount of air as you go up in a vertical direction and the answer is "No."

I think the last chart that was on the board in Mr. Holland's presentation shows the AEC data. The HASP data with the AEC balloon program show a maximum concentration of fission debris with respect to air occurring near the base of the stratosphere. There is not too much of a point to make about it except that it does decrease

with altitude and there has often been the assumption that it was uniform with respect to air. This has led in the past to an overestimate of the stratospheric reservoir.

The third topic has to do with the amount of fission debris in the stratosphere in mid-1958. I said there was 12 megatons of fission product strontium 90 in the stratosphere as a result of testing up to that time. There were a few tests by the United States after mid-1958, and the extensive fall U.S.S.R. series. So the stratospheric reservoir has risen to its largest content ever and that is about 30 megatons of fission product debris in late 1958.

If there is no nuclear testing in 1959, I would expect the reservoir to decrease from 30 to something like 18 megatons by January 1960. It is up to a high level of 30 megatons, if there is no more testing; how does it drop down? Let me just carry it to 1960. It will be like 18 megatons still up in the stratosphere.

Representative HOLIFIELD. I believe it would be worth while for the record and the committee if you would read directly into the microphone your summary when you finish.

Dr. SHELTON. Yes, sir; those are the exact numbers I am covering.

Representative HOLIFIELD. Your voice rises and falls because we can hardly hear you up here. I am not criticizing you.

Dr. SHELTON. I understand. As I say in late 1958 the stratospheric reservoir had its largest content ever and that was about 30 megatons of fission product debris. I would expect it to drop to something like 18 megatons in the stratosphere in January 1960. Let us talk about a material balance for a moment.

In mid-1958 there were about 12 megatons in the stratosphere and there were about 30 megatons on the ground. There are about 30 megatons of fission product debris on the ground. At this time there are about 30 megatons of fission product debris still in the stratosphere. They are about equal. So I would expect the total levels on the ground to essentially double if the remaining stratospheric debris comes down in the same way as in the past.

We have 30 down, there is still 30 up, if it came down the same as in the past, it would double the ground values. The total accumulated amount would only double the hazard we have now.

Representative DURHAM. That would happen regardless of testing?

Dr. SHELTON. That is correct, sir. Whatever level we have now or whatever the hazard there is now as a result of testing it can only double if it all came down as in the past. It turns out that depends on some details. The disparity of the two hemispheres is larger now than it used to be in the past.

Therefore, it will be a little more than double in the Northern Hemisphere. The 30 that is to come down will be coming down more preferentially in the Northern Hemisphere, so it will a little more than double the Northern Hemisphere's value over what exists now.

Representative HOLIFIELD. I think you should make the one distinction that the residence time in the stratosphere will result in a fall on the ground twice as much less the decay that might occur in the time interval. Is that right?

Dr. SHELTON. Yes, sir. It turns out that I have one final point to cover, the last and fourth topic of the HASP results, which has to do with the rate at which the fission debris comes down. The average rate of worldwide fallout or half residence time in the stratosphere is something that we have gotten out of the HASP program. It became abundantly clear last year, during the spring of 1958, that the fission debris from the U.S.S.R. series was being deposited on the ground at a rate very fast compared to the then currently accepted value of something like a 7 year half residence time. The HASP aircraft program monitored the fall 1957 and the later winter 1958 U.S.S.R. detonations, and we observed their mixing in the polar stratosphere and their spread through those now well-known breaks in the tropopauses that occur at about 40° north latitude.

We watched the young fresh Russian fission debris in the spring of 1958 pass through those breaks in the tropopauses. I am sure that the extensive fall 1958 series is passing through the breaks down to the ground much as we saw last year. Their extensive fall 1958 series is coming down much the same way this spring as we watched it last spring. Watching it in rather a detailed way, we would say that the rate of transfer of the Russian fission debris through the breaks in the tropopauses during the spring has about a half residence time of 1 year.

Just watching the rate of change of the stratospheric inventory in the north it looks like about a 1-year or less half residence time for Russian fission debris.

Representative HOLIFIELD. Of course, that is much faster than other calculations that we have had?

Dr. SHELTON. Yes sir. We had no other real good calculations. We were comparing that 1 year with the then currently accepted or currently discussed 7-year residence time. We were sure we had something new. In a similar manner using the measured stratospheric inventory, and computing the total amount injected by the shots that produced the measured inventory, the half residence time for United States and Great Britain shots detonated near the Equator is about 2 years or it could be less. The exact number for the average half residence time is not very important to redefine and to refine once it is established as being as short as several years, since this must be compared to the half life of strontium 90 which is 28 years.

What I am saying is all that goes up, comes down very rapidly compared to the natural decay.

Representative HOLIFIELD. The only significance would be that in the short-lived isotopes if it does come down quickly it would add to the overall deposit on the ground?

Dr. SHELTON. That is right and builds up the external radiation background, of course. What is important is the way it comes down. The stratospheric debris comes down principally through the breaks in the tropopauses, about 40° north or south latitude. The nonuniformity on the ground is an important consequence of the differences in the Northern and Southern Hemispheres, first in their stratospheric content and second to the mode of the transport of the fission debris

through the breaks in the tropopauses and it comes out, as we have seen, concentrated in the temperate latitudes.

Representative HOLIFIELD. The rapid descent adds to the nonuniformity of the precipitation?

Dr. SHELTON. Yes. First we have the disparity of the two hemispheres and the U.S.S.R. debris comes to the ground before spreading to the Southern Hemisphere. Then we have the quick mechanism by which it comes out of the stratosphere through those breaks and it bands more nearly in the temperate latitudes. A final word—we know the physical data quite well. I propose that we know the physical data so much better than its biological effects that any small changes caused by refinement of those small differences that exist among various organizations just can't make such difference when compared to what does it mean biologically.

Suppose we changed any of the numbers I discussed, such as the half residence time from 2 to 3 years. What would we know about the biological consequences? Would we know them any better if it was 2 instead of 3 years.

Would you turn to the summary as you asked?

Representative HOLIFIELD. I think you pretty well covered it.

Dr. SHELTON. Yes, sir. I have covered those four main points.

Representative HOLIFIELD. I think you have covered it since I spoke.

Dr. SHELTON. There were four points which I covered, and they are the A, B, C, and D of the prepared summary.

Representative HOLIFIELD. Thank you very much.

Are there any questions of Dr. Shelton?

If not, we thank you very much for this elaboration on the release that was made this morning and its meaning, and your presentation here, I am sure, is going to be studied very closely.

Dr. SHELTON. Thank you, sir.

(Material submitted by Dr. Shelton follows:)

II. DESCRIPTION OF THE HASP

A. INTRODUCTION

1. The problem of contamination of the entire world population by radioactive fallout from nuclear tests or atomic warfare has been, is, and more than likely will be, for the foreseeable future, a matter of serious concern. It has been accentuated by certain events taking place during the era of nuclear testing. Your attention is called to the incident of the *Lucky Dragon* and her manifest of unlucky fishermen which were contaminated during testing in the Pacific in 1954. Most certainly all news mediums have done their share, particularly within the last few weeks, to focus widespread recognition and attention on the potential hazard associated with radioactive fallout.

2. The Joint Chiefs of Staff, realizing the seriousness and complexity of this problem, requested in the early fall of 1954 that the Armed Forces special weapons project (AFSWP) study and evaluate this problem on a continuing basis. After considerable study of the problem within AFSWP during 1955, it was determined that the largest uncertainty in the prediction of the distribution and concentration of worldwide fallout debris on the surface of the earth is the quantity of fission products in the stratospheric reservoir and the rate and mode of their transfer. Thus, AFSWP, early in 1956, initiated a research program to define and delineate the stratospheric reservoir of fission debris. This program became known as the high-altitude sampling program or Project HASP, and has as its objectives the following:

(*a*) Determination of the distribution and quantity of various radionucleides in the stratospheric reservoir.

(*b*) Determination of the residence times of these radionucleides in the stratospheric reservoir.

(*c*) Determination of the rates of mixing and transfer of these radionucleides within the stratosphere and into and through the troposphere.

B. PLANS FOR ACHIEVING THE OBJECTIVES

1. In order to adequately sample the stratosphere, a system had to be devised which could cover a wide band of latitude, obtain samples through an altitude range extending from the troposphere well into the stratosphere, permit frequent sampling intervals, and collect enough material for accurate radiochemical analysis. Sampling with manned aircraft proved to be the most attractive approach because of the integrated nature of the sample obtained, the tremendous potential coverage, the control of the sample path, and the potential coverage per unit cost.

2. The development and availability to AFSWP of the Lockheed U–2, using a new filter medium of low resistance to airflow at high velocities, yet with high collection efficiency under flight conditions, plus experimental and theoretical aerodynamic investigations showing that a volume of air sampled under flight conditions could be accurately determined, all made Project HASP a real possibility.

3. In light of these developments, certain operational considerations, and the need for establishing scientific facilities and contacts to support the project, the following four-phase concept was conceived:

(*a*) Phase I:
- (1) Development of an atmospheric sampling mechanism
- (2) Flight operation planning and training.
- (3) Establishment of scientific facilities and contacts.

(*b*) Phase II:
- (1) Establishment of a meridional sampling net in the Northern Hemisphere.
- (2) Flight profiles to measure precision of sampling.
- (3) Calibration of the AEC balloon sampler.

(*c*) Phase III:
- (1) Extension of the meridional sampling net to the Southern Hemisphere.
- (2) Study rates of lateral mixing of Hardtack debris.

(*d*) Phase IV:
- (1) Continue the meridional sampling net in the Northern Hemisphere.
- (2) Detailed study of mixing and transfer processes.
- (3) Conduct atmospheric sampling to the North Pole.

4. Operationally it was planned that Project HASP would consist of maintaining a meridional sampling net at about 60° to 70° west longitude, through which most of the atmosphere passes every month or two. It was also planned that the net would have sufficient vertical cross section to sample most of the radioactive debris in the atmosphere. Extrapolation to the higher stratosphere would be made by use of the Atomic Energy Commission Project Ashcan balloon data.

C. ACTIONS FOR ACHIEVING THE OBJECTIVES

1. Scientific aspects:

(*a*) A contract was let in September 1956 with the Institute of Paper Chemistry, Appleton, Wis., for further development and calibration of a filtering medium. The filter medium being used in the HASP is IPC filter paper No. 1478, consisting of cotton fibers with gauze backing. The fibers are impregnated with dibutoxylethyl ptholate, a sticky oily substance which assists with the retention of particulate.

(*b*) A contract was let in February 1957 with Isotopes, Inc., Westwood, N.J., to provide scientific direction and interpretation, and to perform the radiochemical analysis.

(*c*) Dr. Elliott G. Reid, of Stanford University, one of the country's leading authorities on the application of aerodynamic theory to atmospheric sampling mechanisms, was consulted regarding the design and application of a filter-type sampler for the HASP. Based on Dr. Reid's theoretical work in this field, Lockheed Aircraft, Corp. designed and built a sampler having a capability of exposing four filter papers, consecutively. This sampler was installed in the nose position as an integral part of each of the six U–2 aircraft assigned to AFSWP for carrying out the HASP.

2. Operational aspects:

(*a*) The operational responsibility for carrying out Project HASP was assigned to the Strategic Air Command (SAC).

(*b*) The project got underway with the assignment of the six AFSWP U–2's to the 4080th Strategic Reconnaissance Wing (4080th SRW) in August and September 1957. The U–2 is an unarmed single-engine jet aircraft with a crew of one. The range and altitude performance are consistent with the requirements of a research program of this nature. It has tandem landing gear and outrigger wheeled struts, sometimes referred to as "pogo sticks." These struts drop off when the aircraft becomes airborne. Landing is accomplished with the aid of a drag chute and after the landing roll, wingtip skids prevent damage to the aircraft.

(*c*) Following an initial training and testing phase in August to October 1957, at Laughlin Air Force Base, Tex., the sampling aircraft were based at Plattsburg Air Force Base, N.Y., and Ramey Air Force Base, P.R. From these two bases a north-south sampling corridor along the 70° west meridian, and extending from 66° north to 6° south latitude, was monitored systematically from November 1957 through May 1958. During June and July 1958, sampling was conducted only in the vicinity of Puerto Rico. Since September 1958 the aircraft have operated from Ramey Air Force Base and Ezeiza Airport, near Buenos Aires, Argentina, in order to sample the Southern Hemisphere more completely. A corridor along the 63° west meridian, and extending from 38° north to 57° south latitude has been monitored. The Ramey aircraft have made occasional deployments to Plattsburg to check the northern reaches of the sampling corridor. Since these sampling missions are flown over terrain which includes subarctic water and tropical areas having a minimum of emergency landing fields and navigation aids, air rescue support is provided for each mission. C–54 type aircraft are used for this support. It is planned to discontinue sampling in August 1959 fom the Ramey and Ezeiza bases and resume sampling in a corridor along the 100° west meridian during September 1959 from Laughlin Air Force Base, Tex., and a north-central U.S. base. It is also planned to make occasional deployments from Laughlin to Ramey Air Force Base, P.R., to check on the stratospheric inventory of fission debris across the Equator. It is believed that the air sampled along a meridional corridor will be representative of the entire atmosphere as long as sampling is carried out over a sufficiently long period of time. Eventually the whole atmosphere will be carried through the corridor by normal zonal circulation.

(*d*) Two sampling missions, each of which collects 16 samples from the corridor, are scheduled per week. A single sample consists of the particulate matter filtered from between 5,000 and 20,000 standard cubic feet of air. To date, over 1,300 samples have been collected. These samples, with all accompanying data, have been forwarded to Isotopes, Inc., for radio-chemical analysis and interpretation.

D. LARORATORY INVESTAGATION AND EXPERIMENTAL PROGRAMS

1. A scientific program, under the direction of Dr. J. A. Van den Akker, is being conducted at The Institute of Paper Chemistry for the following purposes:

(*a*) Determination of filter paper (IPC 1478, 15 grams per square foot) efficiency under various atmospheric conditions and particle sizes.

(*b*) Development and production of a lighter weight, more efficient filter paper.

2. To carry out this program, a small wind tunnel was constructed which could simulate actual atmospheric sampling conditions. Aerosols of known particle size were generated within the wind tunnel and allowed to flow through filter papers. Samples collected from the airstream in the wind tunnel before and after the filter papers permit determination of filter paper efficiency.

3. Results of this program show that under actual atmospheric sampling conditions simulated in the wind tunnel, IPC filter paper No. 1478 has approximately 100 percent retention for particles with diameters of 0.005 micron and larger. More recent work indicates that it is also highly efficient for even smaller particles.

4. Dr. Reid's effort in determining sampler performance at representative aircraft altitudes and speeds is most important to the results of the HASP. An experimental flight test program under his direction was conducted at Laughlin Air Force Base, Tex., in conjunction with the National Aeronautics and Space Agency laboratory at Moffett Field, Calif., during September 1958. The purpose of this program was to determine as accurately as possible, under varying flight conditions, the volume (standard cubic feet) of air sampled with the nose

sampler using IPC filter paper No. 1478. Preliminary results of this program verify Dr. Reid's theoretical calculations which have been used as a basis of determining the volume of air sampled on a given sampling mission.

5. Isotopes, Inc., effort under the scientific direction of Dr. J. Laurence Kulp, has been devoted to:

(*a*) Planning and coordination with AFSWP regarding flight profiles for the sampling missions which weave the strands of the meridional sampling net.

(*b*) Performing radiochemical analysis—

(1) all samples for total beta decay.

(2) all samples for Sr^{90}, Sr^{89}, and Zr^{95} activity.

(3) A portion of the samples for Ba^{140}, Cs^{137}, Ce^{144}, Be^{7}, and Mo^{99} plus others such as may be desirable or necessary to achieve the objectives of project HASP. It is interesting to note that only one-fourth of the filter paper is normally required for analysis so that most of these valuable and costly samples are available for further checking, for other studies of stable and radioactive nuclides, and/or the geochemistry of the stratosphere.

(*c*) Research and correlation of fallout information bearing on the objectives of the HASP.

(*d*) Interpretation of results and drawing conclusions. All data are reduced to disintegrations per minute per 1,000 standard cubic feet prior to interpretation.

(*e*) Report writing:

(1) Monthly letter reports to AFSWP, including all the latest radiochemical numbers available from the analysis of samples.

(2) Quarterly progress reports covering overall progress on the project.

(3) Technical reports written corresponding roughly to contract dates.

(a) Technical Report No. 1, covering all aspects of the Isotopes, Inc. effort, including results and conclusions from the analysis of all samples collected in the HASP through February 8, 1958, was submitted to AFSWP on September 1, 1958. This report was distributed to Dr. Libby and certain other employees of the U.S. Atomic Energy Commission, Dr. Machta of the U.S. Weather Bureau, Dr. Martell of the Air Force Cambridge Research Center, and to certain members of the Air Force Office of Atomic Energy.

(b) Technical Report No. 2 will be an extension of Technical Report No. 1, and will include interpretation of data, results, and conclusions from the analysis of all samples collected in the HASP between February 8, 1958, and December 1, 1958. It is due for distribution on or about May 15, 1959.

(4) Special reports and briefings are made at the request of AFSWP.

(*f*) A continuous intercalibration program is being carried on with other laboratories, such as the Health and Safety Laboratory, Los Alamos Scientific Laboratory, and Lawrence Radiation Laboratory. This program is being conducted for the standardization of laboratory techniques, and for a cross-check of the radiochemical analysis of HASP samples.

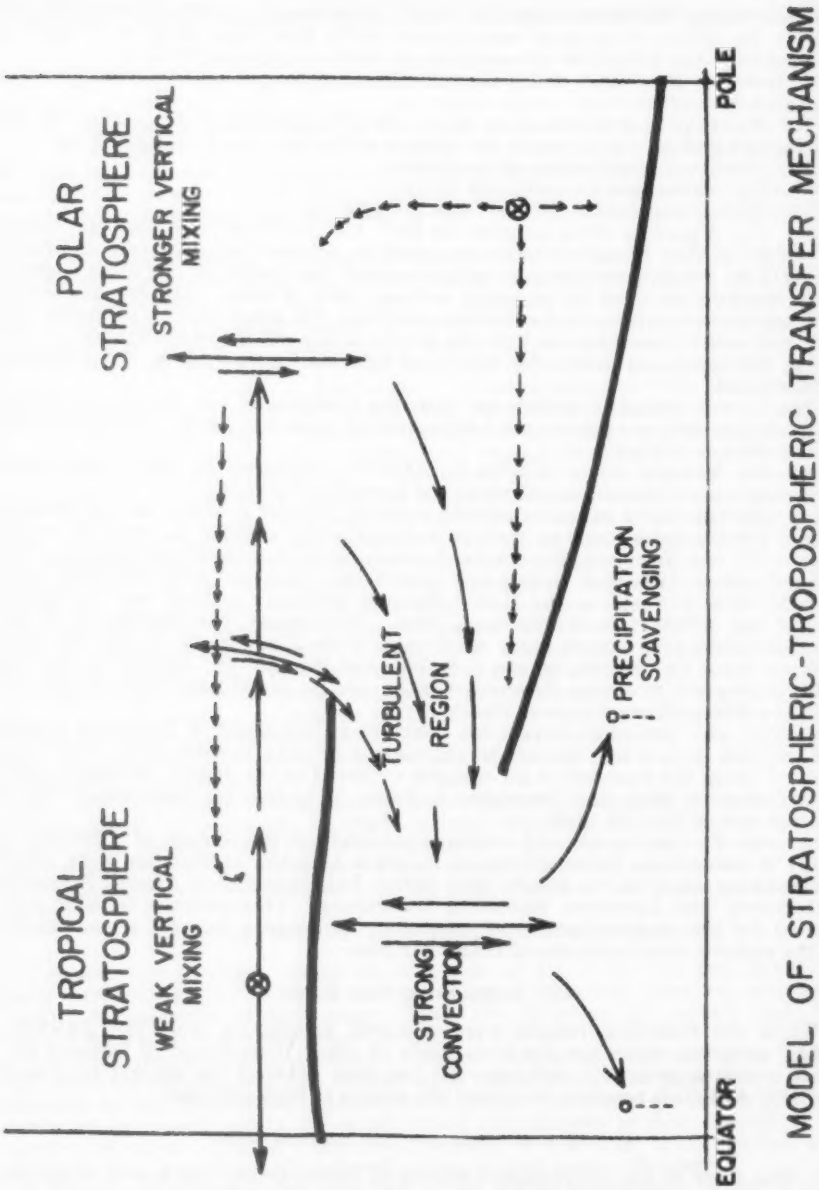
III. Results of the HASP

While the following results were obtained principally from the AFSWP–HASP program, some use has been made of other Department of Defense aircraft sampling programs and some use has been made of the general results of the AEC ASHCAN program to extend the results to high altitudes.

A. The structure of the stratosphere

1. The story of the stratospheric burden of fission debris and how it drips out to form the worldwide fallout begins with a review of the structure of the atmosphere.

2. The tropopause is a region of the atmosphere which separates the upper atmosphere or stratosphere from the lower atmosphere or troposphere. The altitude of the tropopause is about 55,000 feet in the equatorial regions of the earth and the altitude of the tropopause generally decreases with increasing latitude. The altitude of the tropopause is only about 30,000 feet in the polar regions. In the regions of 30°–40° latitude there is an abrupt break in the tropopauses—with the equatorial tropopause higher than the polar tropopause. (See fig. 1.)



3. The temperature in the tropical stratosphere has a uniform lapse rate and is quite stable since the temperatures increase with altitude. However, in the polar stratosphere there is very little temperature gradient and this stratosphere is quite unstable to small variations. Fission products introduced into the tropical stratosphere do not mix rapidly in the vertical direction and only rather slowly in the latitude direction; however, fission products introduced into the polar stratosphere can have rapid vertical mixing and latitude mixing.

4. In the breaks in the tropopauses the jet winds and extreme turbulences are effective in transferring fission products from the stratosphere to the troposphere where the fission products are broug t to the ground principally by rainfall. It is believed that the main mechanism of transfer of fission products from the

stratosphere to the troposphere is through the breaks in the tropopauses, and very little across the tropopauses.

B. VERTICAL AND HORIZONTAL MIXING OF FISSION PRODUCTS IN THE POLAR STRATOSPHERE

1. Fission products introduced into the turbulent polar stratosphere by the U.S.S.R. detonations results in fairly rapid vertical and latitudinal mixing of the fission products and these fission products pass out through the gaps in the tropopauses with a half residence time of about 1 year or less. For instance, about 6 weeks after the U.S.S.R. detonated several large yield weapons in February 1958, the HASP program documented the relatively young fission debris in the polar stratosphere and found that the young fission debris was moving out through the gaps in the tropopauses into the troposphere where its resident time is short—about a month or so.

2. In contrast to this rapid lateral and vertical movement of U.S.S.R. fission debris in the polar stratosphere, it is instructive to give some details of detonations in the equatorial region.

C. HORIZONTAL MIXING OF FISSION PRODUCTS IN THE EQUATORIAL STRATOSPHERE

Since a number of the U.S. detonations during Operation HARDTACK in 1958 contained tungsten, the HASP program was able to document the rate of mixing and spreading of this element in the equatorial stratosphere and the results are generally indicative of the effects of a typical U.S. test series on the stratospheric burden. Tungsten from the first shot of Operation HARDTACK that contained that element passed around the earth in the stratosphere and arrived at the longitude of the east coast of the United States in about 44 days after the shot. During the 44 days the tungsten in the stratosphere had moved westward, it had spread a total of 45° in the north-south directions. About 1 degree per day spread in the latitudinal direction as the fission products pass around the earth in the stratosphere is typical for U.S. detonations at the Eniwetok Proving Grounds and Great Britain detonations at Christmas Island. The fission debris is very strongly stratified in the equatorial stratosphere with its concentration dropping rapidly with respect to altitude in the stratosphere, which indicates weak vertical mixing. Since the U.S. detonations at the Eniwetok Proving Grounds are at about 10° north latitude, the fission products placed in the stratosphere from these shots spreads preferentially to the Northern Hemisphere. Thus, the U.S. detonations at 10° north latitude do bias the Northern Hemisphere stratospheric fission product burden along with the U.S.S.R. polar detonations. This results in there being a larger amount of fission debris in the Northern Hemisphere than the Southern Hemisphere. The HASP program has shown conclusively that there is not a uniform distribution of fission products in the stratospheres of the Northern and Southern Hemispheres, nor would one expect them to be uniform, although this assumption has been made in some of the past analyses. Such an assumption results in an overestimate of the stratospheric fission burden since northern values have been used as a base. Secondly, the HASP program has shown conclusively that there is not a uniform distribution of fission products in the stratosphere with respect to standard cubic feet of air. The concentrations of fission products are largest near the bottom of the stratosphere and decrease relative to standard cubic feet of air with increasing altitude. The assumption of uniformity with respect to air in the stratosphere has also been made in past analyses and results in an overestimate of the stratospheric burden.

D. STRATOSPHERIC INVENTORY OF STRONTIUM 90

In mid-1958, when the HASP data were extended to high altitudes using the AEC ASHCAN balloon data, the HASP program obtained the following stratospheric inventory of Sr^{90} (less the extensive U.S.S.R. fall series in 1958):

Megacuries of Sr^{90} in the Northern Hemisphere	0.8
Megacuries of Sr^{90} in the Southern Hemisphere	0.4
Megacuries in the stratosphere	1.2

Thus, the results are: twice as much stratospheric fission debris in the northern Hemisphere as in the Southern Hemisphere. The total stratospheric inventory of strontium 90 in mid-1958 corresponds to about 10–12 megatons fission yield of strontium 90.

E. THE HALF RESIDENCE TIME OF FISSION DEBRIS IN THE STRATOSPHERE

1. Two difference processes occur with respect to residence time of fission debris in the stratosphere:

(*a*) It is reduced due to the radioactive decay and this is important for the gross activity of the fission products. Short lived elements essentially expend themselves in the stratosphere. For long-lived elements like Sr^{90} (half life is 28 years) and Cs^{173} (half life is 30 years), the radioactive decay in the stratosphere is negligible.

(*b*) The second process that operates on the fission products in the stratosphere is the dripout from the stratosphere or the physical residence time in the stratosphere.

2. Recalling that the HASP program has measured the stratospheric inventory of Sr^{90} to be that corresponding to about 10–12 megatons of fission yield during mid-1958 (less the fall 1958 Russian tests), the best half residence time of Sr^{90} in the stratosphere can be determined by considering the shots that produced the stratospheric Sr^{90} burden. That is, it is known how much Sr^{90} is in the stratosphere, how much was injected into the stratosphere as a function of time.

3. Using all of the available data on United States, Great Britain, and U.S.S.R. detonations the best results are obtained for:

(*a*) A half residence time of 2 years or less for U.S. and Great Britain detonations conducted near the Equator; and

(*b*) A half residence time of 1 year or less for U.S.S.R. detonations conducted at high north latitudes.

4. Other results are:

(*a*) The stratospheric reservoir will contain, in January 1960, about 18 megatons of fission product Sr^{90} and other long-lived isotopes, if there is no nuclear testing in 1959.

(*b*) The stratospheric reservoir has generally contained about 10–12 megatons of fission product Sr^{90} over the past several years.

(*c*) Due to the extensive U.S.S.R. fall 1958 series of nuclear detonations, the stratospheric reservoir of Sr^{90} in January 1959 had its largest content ever and that was about 30 megatons of fission product Sr^{90}.

(*d*) Concerning a material balance in mid-1958, there were about 12 megatons of fission product Sr^{90} in the stratosphere and about 30 megatons of fission product Sr^{90} already deposited on the surface of the earth as a result of worldwide fallout. Thus, most of the Sr^{90} that was produced by nuclear testing up to mid-1958 had already been deposited on the surface of the earth, and if all the remaining stratospheric content deposits in the same way as in the past, the total levels on the ground could be expected to rise by a factor of two.

Representative HOLIFIELD. Dr. Lester Machta, U.S. Weather Bureau.

Dr. Machta, we are glad to have you again before us. You gave us some very valuable information a few years ago. I am sure you have some more to give us today.

STATEMENT OF DR. LESTER MACHTA,[1] U.S. WEATHER BUREAU

Dr. MACHTA. Thank you very much.

Just prior to the last congressional hearings in May and June 1957, it became evident to the speaker that the simple picture of uniform stratospheric fallout was no longer tenable. The amount of stron-

[1] Meteorologist, U.S. Weather Bureau; associated with atomic energy and meteorology since coming to Washington in 1948, now Chief of the Special Projects Section. Born in New York, N.Y., in 1919, graduated cum laude from Brooklyn College in 1939. His meteorological training includes graduate work at New York University (master of arts, 1946) and at Massachusetts Institute of Technology (doctor of science, 1948). During the war he taught meteorology in both a civilian and military capacity for the Air Force. Member of Sigma XI, Pi Mu Epsilon, the American Meteorological Society, and the American Geophysical Society. Recently been given a Gold Medal for exceptional service by the Department of Commerce. Publications in the meteorological literature are numerous and, in recent years, include papers on atomic energy and meteorology. Has been a member of many important Goxernment committees, including the Advisory Committee passing on the meteorological safety of tests in Nevada. Has been instrumental in making the worldwide measurement of radioactivity part of the International Geophysical Year program.

tium 90 in soils was too high in the temperate zone of the Northern Hemisphere to permit the assumption of uniform deposition of stratospheric strontium 90 over the earth's surface.

Apparently, a number of other scientists were simultaneously coming to the same conclusion. In particular, Dr. Stewart, in England, subsequently wrote an excellent paper showing how the British information tended to support nonuniform stratospheric fallout. It is the purpose of this presentation to accomplish the following aims:

1. Describe a meteorological model accounting for nonuniform fallout;

2. Show how the evidence accumulated since 1957 has tended to support the model; and,

3. Describe the practical consequences of the model.

The atmosphere is conventionally divided into two layers as shown in figure 1. A lower part, the troposphere, contains our everyday weather. Above the troposphere is the stratosphere in which there are essentially no clouds and little turbulence. The tropopause is the boundary separating the two layers. It varies in height with season and latitude lying mostly in the range from 35,000 to 55,000 feet.

The tropopause suffers a break in the temperate latitudes as seen in the figure. The break is associated with the jetstream, a strong west-east current of air.

It has been frequently pointed out that the nuclear clouds from less-powerful low-altitude explosions remain entirely within the troposphere. The radioactivity from these clouds is washed out of the atmosphere quickly, about half being cleansed each month.

In this short period, the radioactive particles do not have time to mix appreciably in a north-south direction while being carried rapidly around the world. More powerful tests or those which are fired at high altitudes, inject their debris into the stratosphere. The absence of rain scavenging the very slow vertical mixing account for the longer storage of these particles in the stratosphere.

If the particles are large enough, they would simply settle out of the stratosphere. But while we have no measurements of the size of the radioactive particles, it is customary to assume that many of them move only with the air currents. It is these air movements which we will now describe.

About 10 years ago two British scientists, Drs. Brewer and Dobson, analyzed observations of the amount of moisture in the stratosphere. They concluded that the very dry air found there could best be explained by assuming it passed through the very cold temperature of the equatorial tropopause. That is, the air, in moving through the region of the equatorial tropopause, where the temperatures are very low, condenses out its moisture before entering the stratosphere.

This circulation, as interpreted by Dr. Stewart in England is shown in figure 2. The vertical scale is altitude. The horizontal scale is latitude and extends from pole to pole. The dotted lines are the average tropopause positions. The arrows show the circulation just mentioned.

The air rises into the stratosphere in the equatorial regions. Since an equal amount of air must leave the stratosphere, the arrows show this exit as well. The Brewer-Dobson model states that air enters the stratosphere primarily in equatorial regions and leaves mainly in the temperate or polar latitudes.

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What fallout predictions will this circulation suggest? There will be a strong tendency for radioactivity in the stratosphere of one hemisphere to enter the troposphere in the temperate or polar latitudes of the same hemisphere. Since all of the important United States and U.S.S.R. stratospheric injections took place in the Northern Hemisphere, the greatest deposition of the stratospheric debris then will appear in the north temperate latitudes.

A large amount might also be expected in the Arctic except for the fact that the precipitation amounts are so small that the amount of fallout is proportionately low. The model also predicts that injections made in polar latitudes will leave the stratosphere more quickly than those at 11° N., because they do not have to go as far to leave the stratosphere.

The arrows and lines high in the Arctic winter stratosphere are related to the fact that the sinking motion in the stratosphere may be primarily a late winter or early spring phenomenon. In fact, Brewer and Dobson use the seasonal variation of ozone in the temperate and polar latitudes to claim that the stratospheric air enters the troposphere mainly in the late winter or spring. We will look for a similar season variation in the radioactivity which comes out of the stratosphere.

Before showing fallout patterns, a word of caution about the model. The Brewer-Dobson picture is not universally accepted by all meteorologists. There are still unresolved questions which are asked of it. Other meteorological circulations and phenomena also may explain the observed fallout situation but at the moment we think the Brewer-Dobson model is best.

The picture we are trying to convey is as follows: Imagine a very slowly rising fountain of tropospheric air entering into the equatorial region of the stratosphere, spreading poleward and sinking back into the troposphere mainly in the late winter or spring.

The best information on fallout of strontium 90 over the world is given by the soil samplings in the spring of 1958. We have plotted these soil samples on a graph to illustrate the north-south profile. In figure 3, the verticle scale shows the amount of strontium 90 in millicuries per square mile. The horizontal scale is latitude, plotted in such a way as to account for equal areas of the earth at different latitudes.

The dots are samples collected outside of the continental United States but analyzed by the U.S. Atomic Energy Commission. The triangle is a German sample analyzed by the Germans. The high dot at 21° North is a special sample collected in a very heavy rainfall region in Hawaii.

We have analyzed the soil sample results in the light of the rainfall distribution over the globe and have deduced an average north-south profile given by the dashed line. It is very similar to the analysis made by Dr. Alexander, of the Department of Agriculture. It is clear that the total strontium 90 fallout is a maximum in the north temperate band. There is a weak suggestion of a secondary peak in the South Temperate Zone.

This profile represents all of the strontium 90 fallout which has been deposited remote from the proving grounds. To obtain the stratospheric fallout, we must subtract the tropospheric part. Recall

that the tropospheric radioactivity neither falls out near the proving grounds nor enters into the stratosphere.

Using the production of tropospheric radioactivity as estimated by Dr. Libby and its distribution, determined insofar as possible from actual observations, we have constructed a theoretical north-south profile of tropospheric fallout. This is shown in figure 4 as the dotted lower line. The uppermost dashed line is a tracing of the mean profile derived from the soil findings, an exact copy of the line from the previous figure. If one subtracts the tropospheric fallout from the total or soil fallout, the remainder is the stratospheric fallout. The heavy line labeled stratospheric has been obtained by this subtraction.

Most of the strontium 90 fallout is stratospheric according to this analysis. For this reason, the validity of the nonuniform stratospheric fallout does not depend on the details of method.

If you will recall the prediction of the Brewer-Dobson model locating the exit of stratospheric air poleward of the equatorial latitudes, I think you will agree that this picture tends to agree with the model.

It appears from the fallout pattern that two refinements may be applied to the model. First, the exit appears to be in the temperate rather than polar latitudes. The arguments for this will be better justified by a study of air concentration. Second, some of the strontium 9 mixes into the Southern Hemisphere by horizontal mixing.

While the analysis of soil samples provides the accumulation of fission products in the ground, collections of rainwater can yield the rate of fallout. We shall use the rainfall collection results to show two things: First, to confirm the uneven stratospheric fallout just derived from the soil samples and second, to study the seasonal variation in the rate of fallout.

The total fallout during the period from July 1957 through June 1958 is shown on figure 5. The vertical scale is the strontium 90 fallout in millicuries per square mile during this year and the horizontal scale is latitude as in the previous figure. Both United States and United Kingdom data are plotted. Where the record is slightly incomplete, we have made corrections.

The three British points—the dots—which stand out, are located at stations with high rainfall. The rainfall results show the same higher fallout in the north temperate belt as was found in the soil analysis. A Southern Hemisphere peak is absent, but the amount of information is very small.

There were many atomic tests during this period and some of the fallout in the rainwater is tropospheric. We are able to estimate the fraction of tropospheric fallout from an analysis of the short-lived fission products which are also created by the explosion.

This analysis indicates that less than 25 percent of the fallout in the North Temperate Zone was tropospheric and less than 10 percent in the Southern Hemisphere. If these fractions, 25 percent and 10 percent, are subtracted from the fallout amounts shown in figure 5, the remainder will be stratospheric.

It is clear that a removal of 25 or even more, of the peak in the North Temperate Zone will leave the maximum in the same place. This, I feel, is independent evidence of the greater stratospheric

fallout in the north temperate band which we deduced from the soil data.

The rainfall collections can also be studied to detect seasonal variations in the fallout rate. The station with the longest record in the United States is New York City whose fallout history is given in figure 6. The vertical scale is the amount of fallout—actually rainout—in millicuries per square mile during the month indicated along the horizontal.

The record begins in 1954 and shows a gradual increase in the average monthly fallout rate during the 5 years shown in the figure. But more striking is the higher fallout rate which appears in the spring and smaller rate in the autumn of each year.

This higher fallout in the spring is not necessarily associated with heavier rainfall. The monthly precipitation amounts are graphed along the bottom of the chart. An analysis of the shorter lived fission products also conforms the fact that most of the fallout in the spring is old or stratospheric strontium 90.

By coincidence, the United States conducted tests in the spring of the years 1955 and 1956. The tropospheric fallout could have accounted for the heavier spring fallout in these years. But in 1957 the Nevada test series lasted from about June to September. Despite this, the fallout rate at New York decreased in the usual seasonal fashion in the late summer and fall of 1957. This indicates that the tropospheric fallout probably does not play a major role in the seasonal variability of fallout.

Figure 7 illustrates the seasonal variation for 12 north temperate latitude stations during the period from July 1957 through June 1958. The minimum in the autumn and maximum the following spring is quite apparent. The dotted curve is the fallout history at two British south temperate stations.

There is a slight suggestion of a maximum in the Southern Hemisphere spring and a minimum in the autumn. Five equatorial stations demonstrate no systematic time fluctuations.

The seasonal variation of the fallout tends to support the Brewer-Dobson model. It alerts us to the control which the atmosphere exercises over the exchange of air between stratosphere and troposphere.

Representative HOLIFIELD. A question from Mr. Ramey at this point, Dr. Machta.

Mr. RAMEY. I believe one of the other witnesses is going to suggest that this seasonal variation may be explained not by reason of the seasonal aspects but by reason of the fact that the Russians held their tests in the previous fall.

Do you have any comment to make on that contention as to the evidence supporting that?

Dr. MACHTA. Yes. We have had quite a discussion of this last week at the meeting of the National Academy of Sciences, and my view is still that the seasonal variation is a meteorological phenomenon. The fact is that in the previous fall the stratosphere of the polar and temperate regions was filled up by Russian tests in some of these years.

But there was no U.S.S.R. stratospheric injection in the autumn of 1954 and yet figure 6 shows a maximum in the spring of 1955. There are other arguments which Dr. Martell and I have had describing

the reasons for differences of opinion which we have on this matter.

Representative HOLIFIELD. You may proceed.

Dr. MACHTA. Air concentration: Fallout measured by soil sampling or in rain suffers from a defect as far as the previous interpretation is concerned. The heavier fallout in the spring or in the North Temperate Zone might somehow be the result of more efficient rain scavenging at one time or place than at another.

It is comforting, therefore, to have the Naval Research Laboratory measurements of ground level air content. We will use these air observations to study three items: First, the nonuniform fallout and seasonal variation; second, the faster Russian fallout; and third, results of a tracer experiment.

Four monthly north-south profiles of the strontium 90 content of air are shown in figure 8. The vertical scale is the number of disintegrations per minute—an amount of radioactivity—in 100 cubic meters of air. The horizontal scale is latitude, once again.

The profile for each month is shown with a hemisphere and appears as a dotted line. April is the highest with a solid line. During all months, the peak air concentration is in the north temperate belt. It is displaced slightly south of the peaks in the soil and rainfall profiles. This may be due to the fact that the air sampling stations are along the U.S. east coast where storminess is displaced farther south than for the world average.

A secondary peak appears in the South Temperate Zone. This graph contains the best evidence of a strontium 90 peak in the south temperate region yet obtained. It is not due to tests in Australia since there were none after October 1957.

A seasonal variation in air content is evident even in this short record. In the Northern Hemisphere, the content increases from winter—January—to spring—April—and decreases in the Southern Hemisphere from summer—January—to autumn—April. Thus, both the uneven distribution of strontium 90 and the suggestion of a season variation similar to that found in the rainwater add to evidence supporting, but not proving, the Brewer-Dobson model.

The second point derived from the air content observations deals with a prediction we made in 1957. This is the faster rate of fallout from Russian high yield nuclear tests as compared to U.S. Pacific tests. The massive Russian injections into the polar stratosphere in October 1958 probably increased the stratospheric strontium 90 content by as much as 2½ times.

By March 1959, in figure 9, most of the ground air concentration of fission product radioactivity is probably of stratospheric origin. The certical scale on the graph is the gross fission product air concentration, the horizontal is the same latitude scale as on earlier figures.

The concentrations in March 1959, as well as January and February 1959, when compared to the corresponding months of 1958, show an increase greater than the 2½ expected from simple ratios of stratospheric content.

The conclusion is drawn that recent Russian radioactivity is being removed from the stratosphere faster than other earlier injections. But the conclusion is still, as far as these data are concerned, very tentative. First of all, we should make the comparison with

strontium 90, not gross fission products, but the strontium 90 information is not yet available.

Second, there is uncertainty concerning the stratospheric ratio of less than 2½ since it depends somewhat on the stratospheric removal rates. One can also note the absence of any significant increase in Southern Hemisphere concentrations in the figure from 1958 to 1959.

The evidence, such as it is, suggests that injections made in north polar latitudes will be removed from the stratosphere more quickly than those at equatorial latitudes. The deposition of this debris then appears in the North Temperate Zone.

The final piece of evidence related to nonuniform stratospheric fall out is, in my view, the most convincing. During the summer of 1958 a completely new substance, tungsten 185, was uniquely created in readily detectable amounts during the Hardtack test series in the Marshall Islands.

By January 1959, the date of the results shown in figure 10, most of the tungsten must have moved through the stratosphere before being sampled at ground level. The vertical scale is the tungsten 185 concentration and the horizontal scale is latitude. Though the amount of information is limited, there is evidence of much greater tungsten 185 content in the North Temperate Zone, the same region in which the deposited stratospheric strontium 90 is a maximum. The meaning of this information is clear. A tracer added to the stratosphere at 11°N. is carried by atmospheric motions poleward in the Northern Hemisphere. More of it appears in the Northern Hemisphere and little is present in the equatorial latitudes where it was injected.

Mr. RAMEY. I believe the Commission representative made a comment that the evidence was not really all in yet on this tungsten as a tracer, and it would take a few months more before he could really come to any conclusion. Do you have any comment on that?

Dr. MACHTA. Yes. It would be much more convincing if we had information beyond January 1959 to support this conclusion. However, it is my view, in the light of Dr. Shelton's comments about the uneven stratospheric distribution of tungsten 185, plus the uneven distribution at ground level air concentration, plus the uneven distribution of fallout which is shown in my appendix, represent a fairly convincing picture. What is injected at 11° N. just above the tropopause is coming out preferentially in the temperate latitudes of the Northern Hemisphere. We will have more evidence on this situation several months from now.

Representative HOLIFIELD. You are confident that the succeeding information will tend to confirm your conclusions of today?

Dr. MACHTA. I am, sir.

In addition to information just developed, there are several features which are of interest. These will be summarized very briefly.

First, the stratospheric sampling program clearly indicates a nonuniform distribution, both vertically and horizontally. For example, more strontium 90 was found in the Northern than Southern Hemisphere. This nonhomogeneity is inconsistent with the concept of a mean residence time. In this concept, a certain fraction of the entire stratospheric content is removed each year.

Second, except for comments about very fast Russian fallout, to be mentioned in a moment, the disagreement about the residence time of stratospheric debris is a secondary matter, especially since the concept

is not correct anyhow. The total deposited strontium 90 will increase by only 20 percent if the residence time is reduced from 10 years to zero years—that is, infinitely fast fallout. I feel that the vital problem, as Dr. Shelton agrees, is the degree of nonuniform stratospheric fallout rather than the residence time.

Mr. RAMEY. You mentioned Dr. Shelton's information several times. How good do you think that information is? How conclusive are the results of this information that he has of direct sampling?

Dr. MACHTA. I have complete confidence in it but I think Dr. Shelton should speak to that subject rather than I.

Mr. RAMEY. It might be thought to be a little self-serving. That is why we wanted to get some other corroborative evidence on his data.

Dr. MACHTA. The information on tungsten 185 which he has reported was received only from Dr. Shelton. I have not looked at it independently.

The conclusions which follow from the previous discussion can be summarized as follows:

1. The observed total strontium 90 fallout or air concentration is unevenly distributed over the earth with a peak in the North Temperate Zone. There is also a seasonal variation with a maximum in spring.

2. There is strong evidence that the nonuniform distribution and the seasonal variability are derived primarily from stratospheric strontium 90.

3. There is evidence that stratospheric fallout from polar latitude (Russian) explosions may be coming out faster that the equatorial injections. The same faster fallout will result from any similar injections either in the temperate or polar regions.

What are the practical consequences?

1. In predicting future fallout from the stratosphere, one must assume a nonuniform pattern with values in the temperate latitudes averaging 2½ times the world average. The hazard from stratospheric fallout in this region is thus also increased by 2½ over what it would be if fallout from the stratosphere were uniform. In addition, local nonuniformities are superimposed on this latitudinal unevenness.

2. Faster Russian fallout means two things: First, a greater degree of nonuniform fallout than the 2½ estimated from past fallout; second, if the residence time becomes much less than a year, which is possible, there will be an additional health hazard from fission products with half-lives of a few weeks to a few years.

3. If Russian debris is leaving the stratosphere faster than previous strontium 90 injections, this spring promises to produce the highest fallout rate of any spring thus far and if tests cease after this year.

4. If the proposed circulation model is correct, future fallout will still be peaked in temperate latitudes even if the test ban continues. In fact, because of the large Russian injections the nonuniformity will be increased.

Representative HOLIFIELD. I might say we have had some complaint from the members of the press that we are giving them so much information that they can't digest it today, but the time of the scientists and the committee is limited and we must put this material into the

record. It will take many months of study, probably, to realize the significance of all these facts which have been introduced even up to now and we are going to introduce more.

I might say at this time that we have a great deal of confidence in your testimony, Doctor, because the testimony that you gave us 2 years ago has proven to be pretty correct. You were a pretty good prophet at that time on some of the things that have developed since then.

This is a valuable contribution to our hearing, and the supporting material which you have submitted here with the charts will be made a part of the permanent record.

(The documents referred to appear on p. 787.)

Representative HOLIFIELD. Are there questions of Dr. Machta?

Representative DURHAM. I have just one, I believe, Mr. Chairman.

Dr. Machta, in your last conclusions, (2) and (3), is there any evidence at the present time that such a thing is happening and that the Russian debris is falling out faster?

Dr. MACHTA. Yes, sir; there is evidence that it is falling out faster than debris injected from equatorial tests. I believe there is such evidence. I believe this is not a disputed point at the moment.

Representative DURHAM. You made a statement there that is a little bit large, because if the Russian debris is leaving the stratosphere faster than previously, the strontium injection this spring will be at the highest rate.

Dr. MACHTA. The evidence suggests that the fallout rate this spring is very high. I made the prediction that once we are over this spring, the fallout rate will be much smaller in the future.

Representative DURHAM. The evidence thus far proves it to be a fact?

Dr. MACHTA. It is a fact.

Representative HOLIFIELD. This fact only remains as long as the bomb test moratorium continues. When you start additional tests, if they are started, then your future springs will continue to grow in total fallout.

Dr. MACHTA. This is especially so if the Russians test high yield explosives in the temperate or polar latitudes.

Representative HOLIFIELD. We can say as laymen that the degree of fallout proportionately from a same size weapon exploded in the north latitude by the Soviets will produce a great deal more contamination of the north temperate latitudes than the same size test conducted at our testing ground in the Tropical Zone or near the Equator in the South Pacific?

Dr. MACHTA. It is my estimate that the debris injected into the stratosphere at 11° N. will have approximately two-thirds of it deposited on the Northern Hemisphere, a ratio of 2 to 1 between hemispheres, whereas all of the Russian debris will fall out on the Northern Hemisphere.

Representative HOLIFIELD. I think this is a very significant factor. It is even more important when you apply it to a potential future war with nuclear weapons. Are there any other question of Dr. Machta?

If not, thank you very much. Dr. Machta.

Dr. MACHTA. Thank you, sir.

(Dr. Machta's supporting material follows:)

Supplementary Data

Soil Data

Figure 11 shows the world-wide distribution of Sr-90 in foreign soils. These soils were carefully collected from representative sites by Dr. L. T. Alexander of the Department of Agriculture in 1958. The figures give the values in millicuries of Strontium-90 per square mile. From the limited number of soil samples and knowledge of the world-wide distribution of precipitation, assuming that aside from latitudinal variations, precipitation is the principal agent in the deposition of Strontium-90, it is possible to draw a smoothed world-wide pattern of Strontium-90 deposition. Isolines of Strontium-90 deposition are shown. These are based on observed representative soil deposition where available, using the precipitation patterns to interpolate between stations. The lines are somewhat idealized, since large variability in precipitation over very limited areas can occur in certain cases, which in turn would result in large variations in deposited Strontium-90. The isolines on Figure 11 were used to arrive at the latitudinal profile of world-wide Strontium-90 deposition shown on Figure 3.

Since the total deposition measured in the soil is a result of both stratospheric and tropospheric fallout, it is necessary to estimate the tropospheric contribution in order to determine the stratospheric component. Libby (1959) has given a procedure for making this estimate. Using Dr. Libby's estimates, the production of tropospheric Strontium-90 at the end of 1957 and 1958 and the announcement of tests during the spring of 1958, an estimate of the tropospheric fallout was made. Experience has shown that, on the average, debris is deposited over a wide belt of latitude, with the peak deposition in the approximate latitude of the test site. The lower portion of Figure 12 shows the observed tropospheric profile from two individual United States test series, on a relative scale. Assuming that tropospheric debris from any test series tends to spread out in the same fashion, the distribution of tropospheric Strontium-90 fallout from all tests through the Spring of 1958 is shown in the upper part of Figure 12. The values have been corrected for radioactive decay.

Figure 13 shows the mean latitudinal distribution of precipitation

(upper) and a smoothed curve of stratospheric deposition. It is evident that the main features of the deposition are influenced by latitude, with the precipitation pattern playing a secondary role. However, at any given latitude, it is felt that the variability in precipitation is the determining factor in the amount of stratospheric rallout that occurs.

Rainfall Collection Data

Figure 4 shows the specific activity of Strontium-90 per inch of rain for the period July 1957 - June 1958. Figure 15 shows the seasonal variation of the specific activity in several latitude bands, confirming the spring maxima and fall minima both in the southern and northern hemisphere.

It is interesting to see if the stratospheric content of Strontium-90 is directly related to the deposition on the ground. Figure 16 shows the estimated concentration of Sr-90 in the stratosphere based on the AEC high-altitude balloon flights (Project Ashcan). These data are admittedly sparse and uncertain, data at only four locations (black dots), but the relative concentration from one latitude to another should have validity. The dotted curve shows an estimate of this concentration, while the lower solid curve shows the specific activity of Sr-90 in precipitation. It is evident that no direct relationship applies, and that there must be preferential regions for removal of debris from the stratosphere, or for deposition on the ground, in the temperate latitudes. An interesting confirmation of the meteorological model is indicated by the preliminary Tungsten-185 results from rainfall collections. Since this isotope was unique to the Hardtack Pacific series which ended in July, 1958, the data in Figure 17, especially during November and December, 1958, show principally stratospheric deposition from this series alone. The temperate latitude fallout peak is evident as it was in Figure 10.

Air Concentration

Figure 18 shows the 12-month change in air concentration of gross fission products for four months prior to that shown in Figure 9. It is apparent that the same remarks made in connection with the March 1958-1959 data apply to these months.

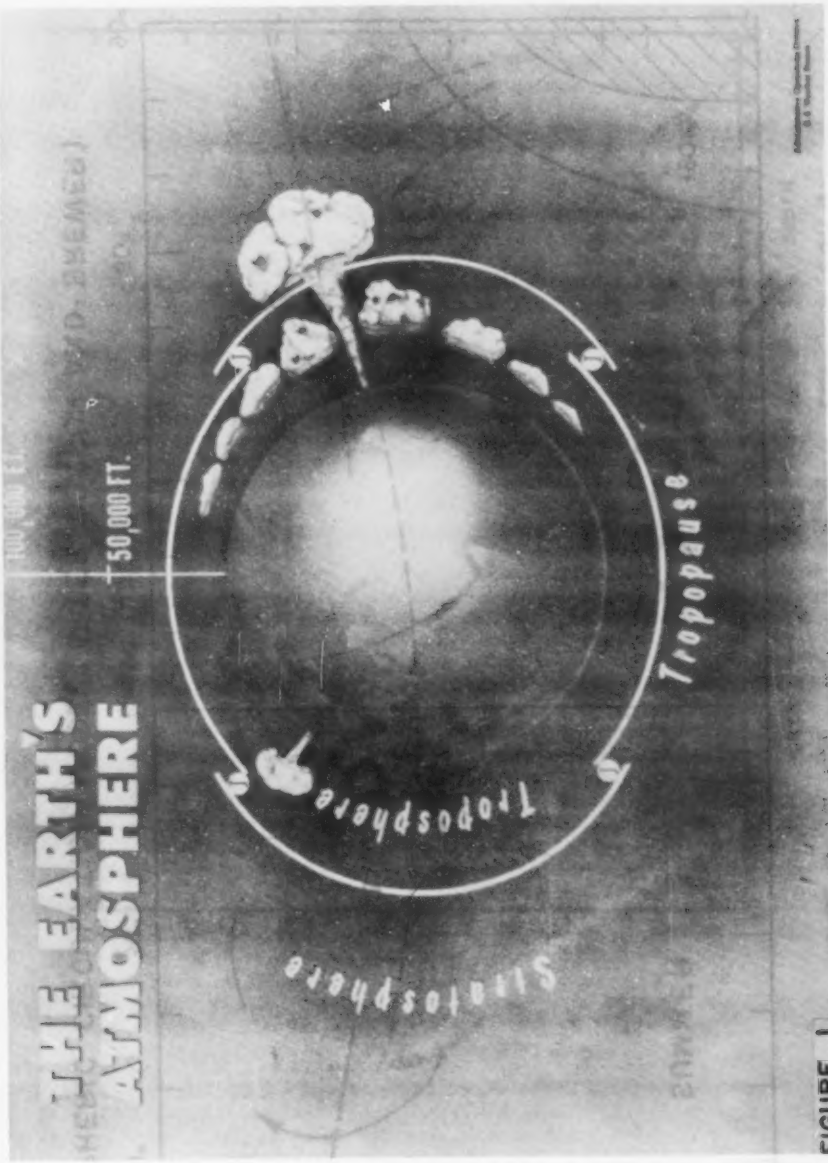
THE EARTH'S ATMOSPHERE
50,000 FT.
Tropopause
Troposphere
Stratosphere

FIGURE 1.

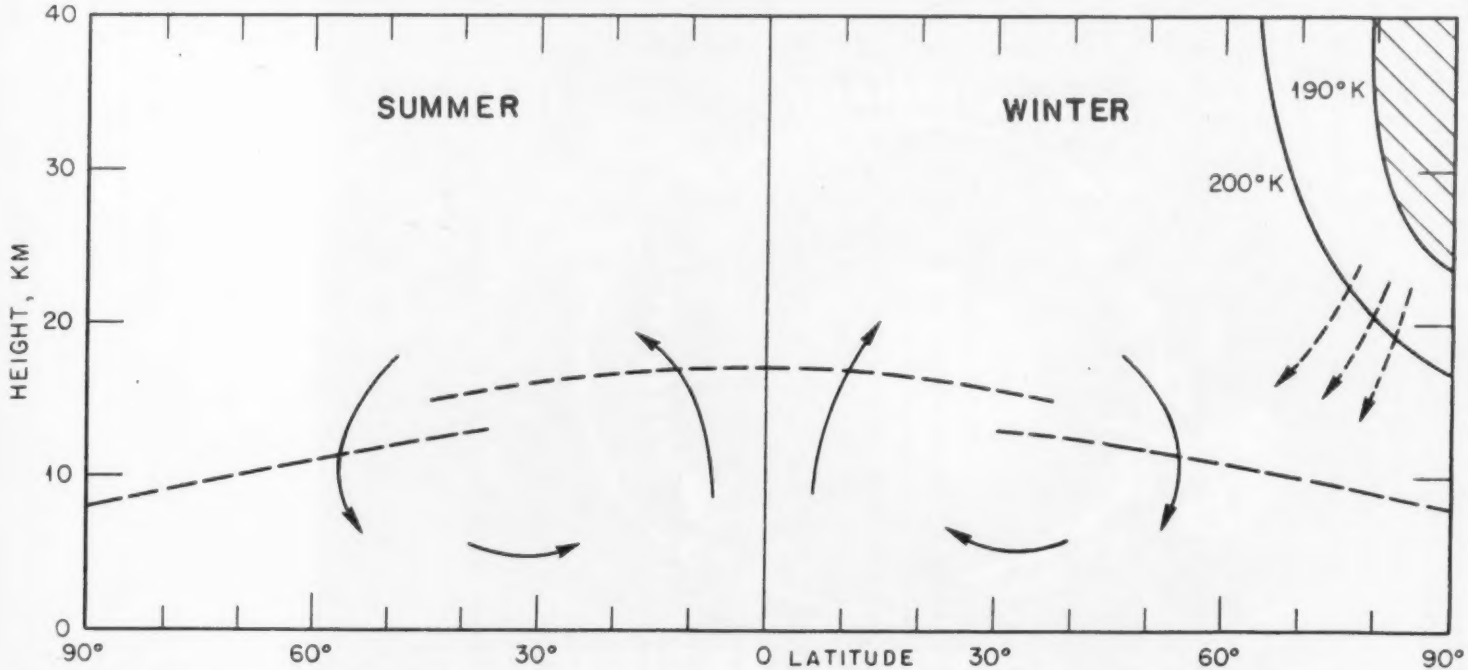

FIGURE 2 ATMOSPHERIC CIRCULATION MODEL (AFTER DOBSON AND BREWER)

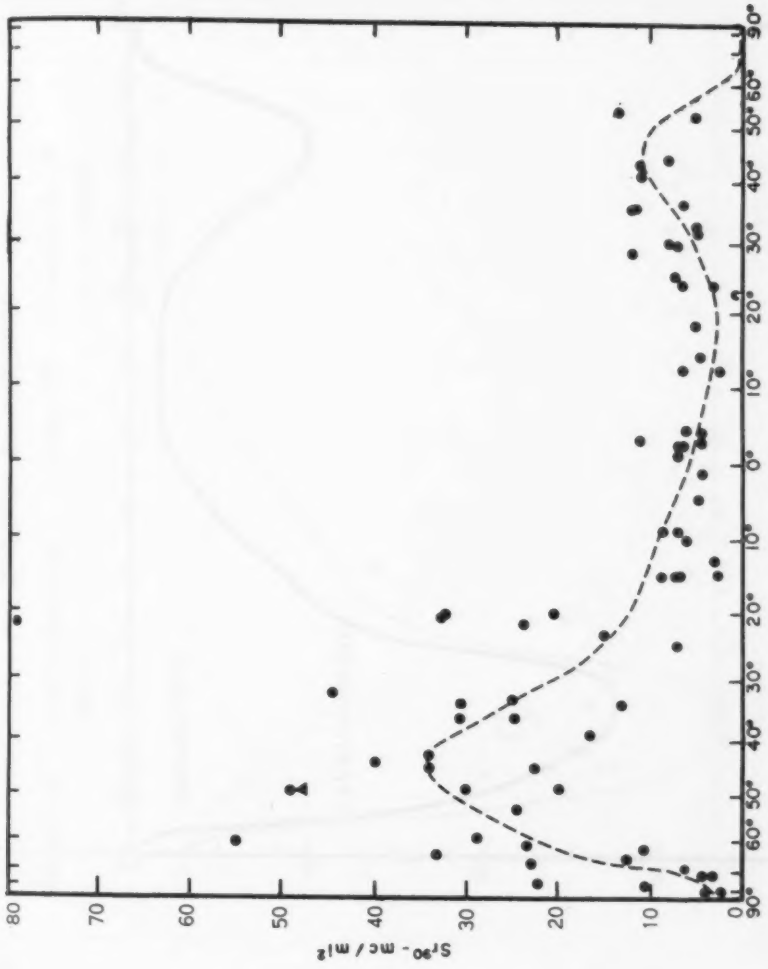

FIGURE 3 STRONTIUM-90, 1958 FOREIGN SOILS

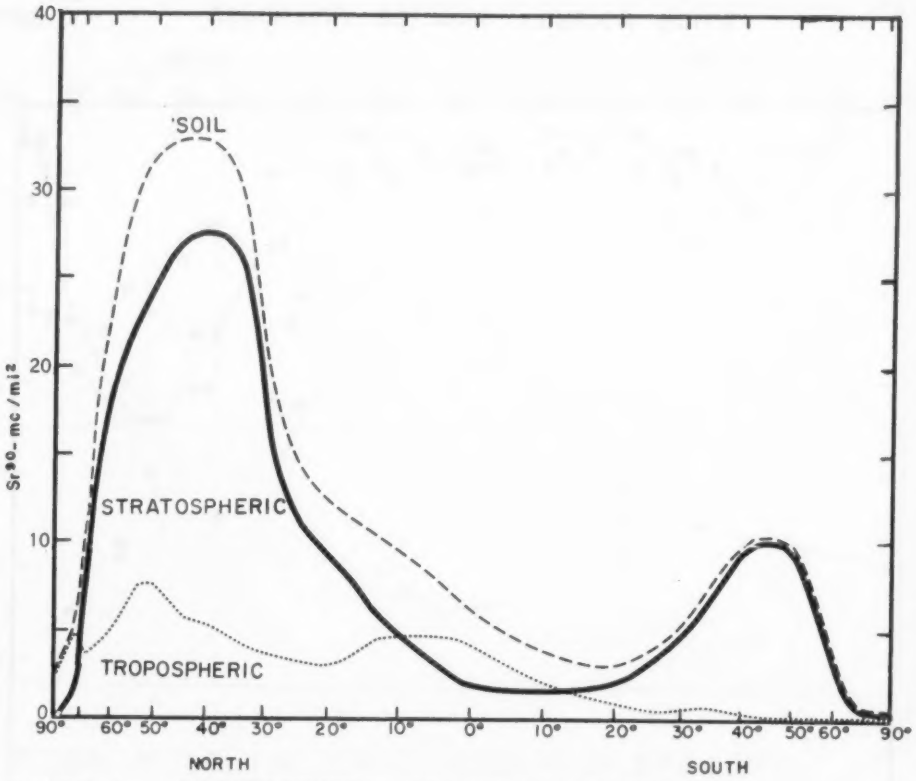

FIGURE 4 STRATOSPHERIC STRONTIUM-90 DEPOSITION THROUGH SPRING, 1958

FIGURE 4 STRATOSPHERIC STRONTIUM-90 DEPOSITION THROUGH SPRING, 1958

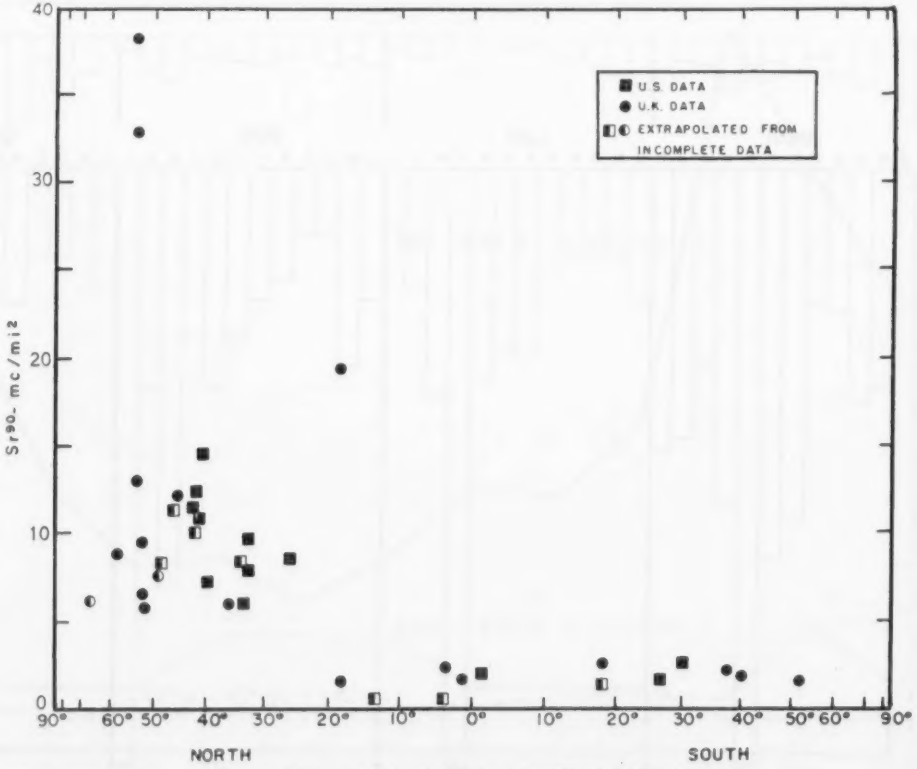

FIGURE 5 TOTAL STRONTIUM-90 DEPOSITION, JULY, 1957 - JUNE, 1958

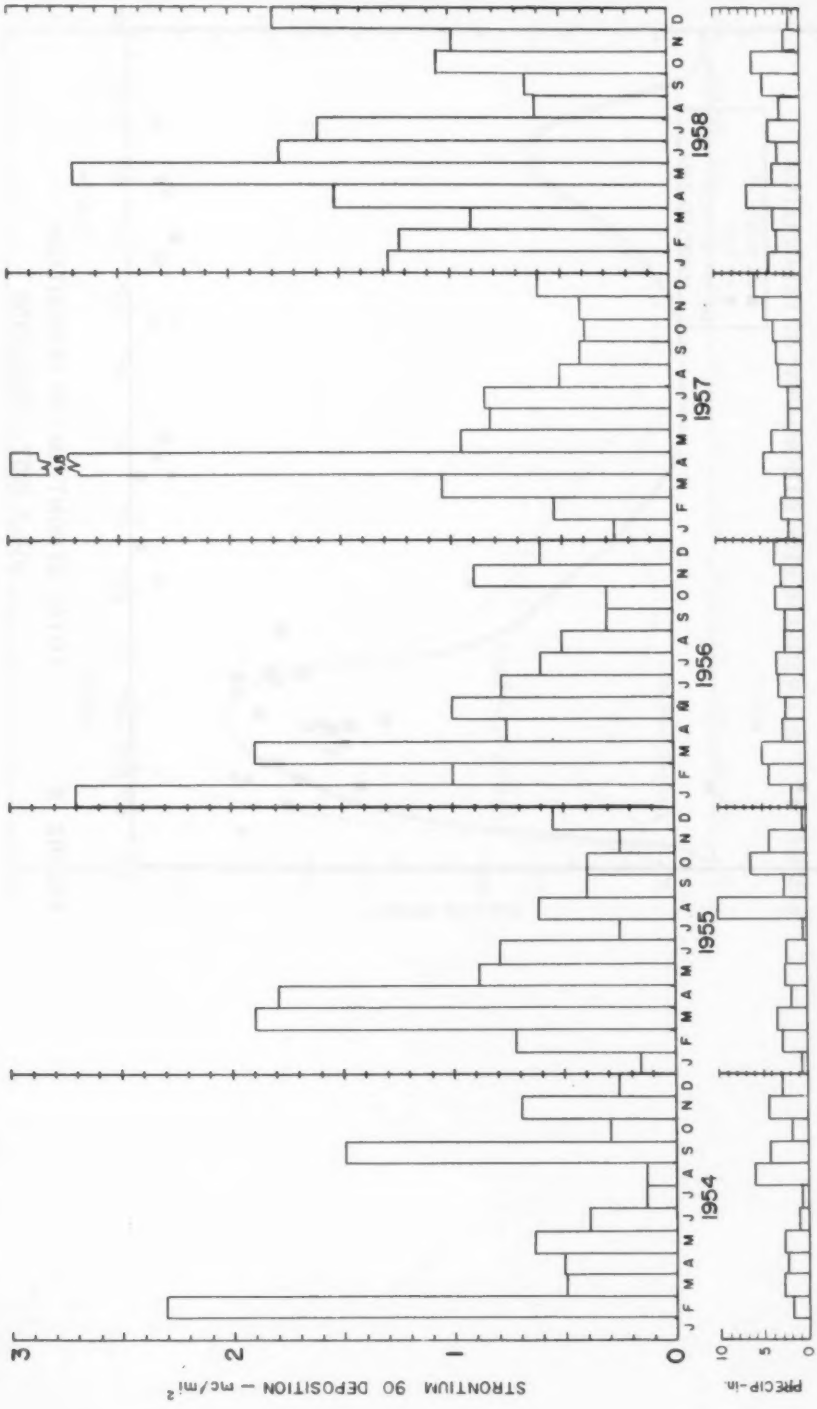
STRONTIUM 90 DEPOSITION — mc/mi²
0
1
2
3
PRECIP-in.
0
5
10
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1954
1955
1956
1957
1958
NEW YORK

FIGURE 6

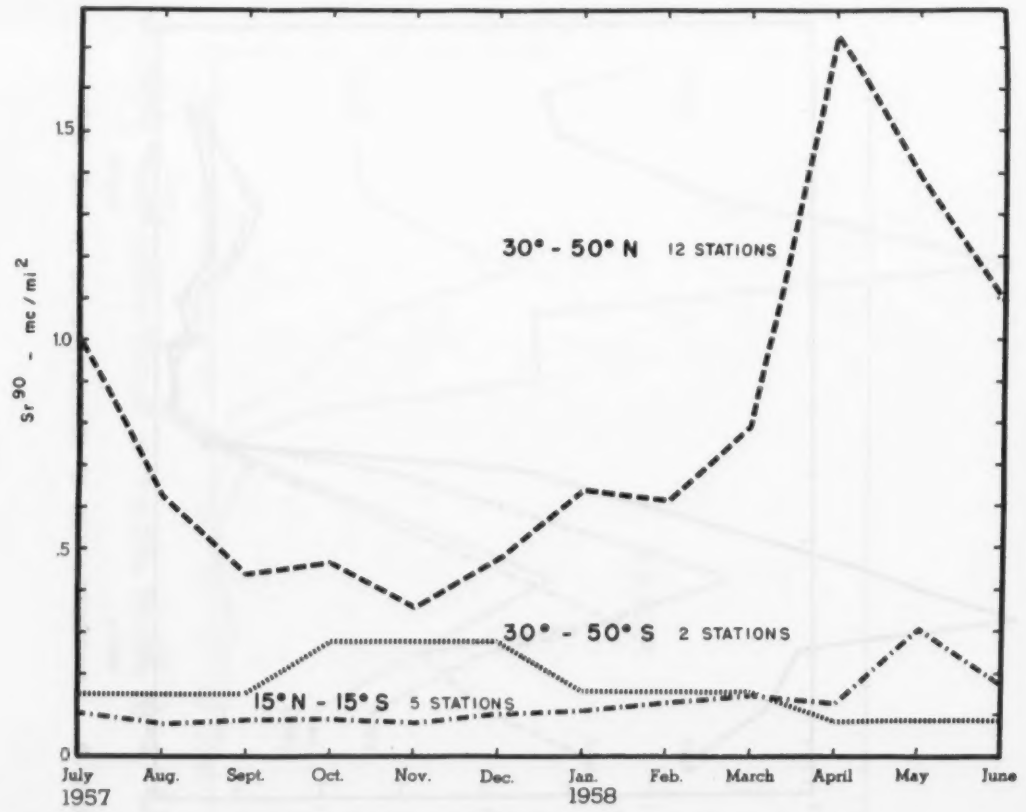

FIGURE 7 AVERAGE MONTHLY DEPOSITION OF STRONTIUM-90

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FIGURE 6 NEW YORK

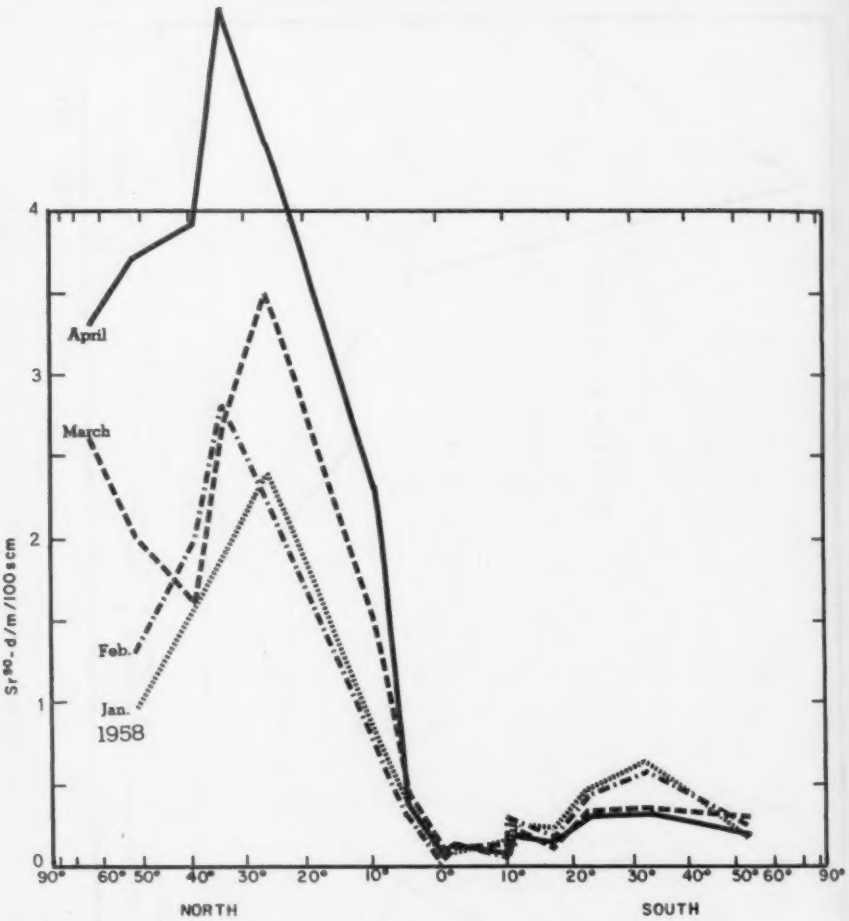


FIGURE 8 CONCENTRATION OF STRONTIUM-90 IN THE AIR

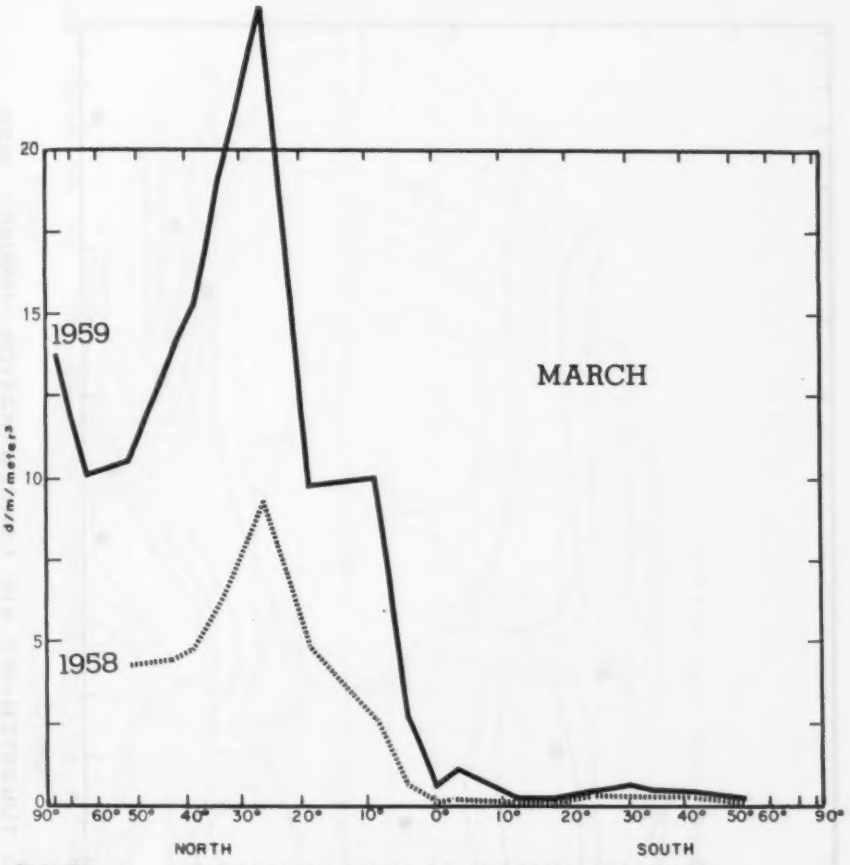


FIGURE 9 AIR CONCENTRATION OF FISSION PRODUCTS

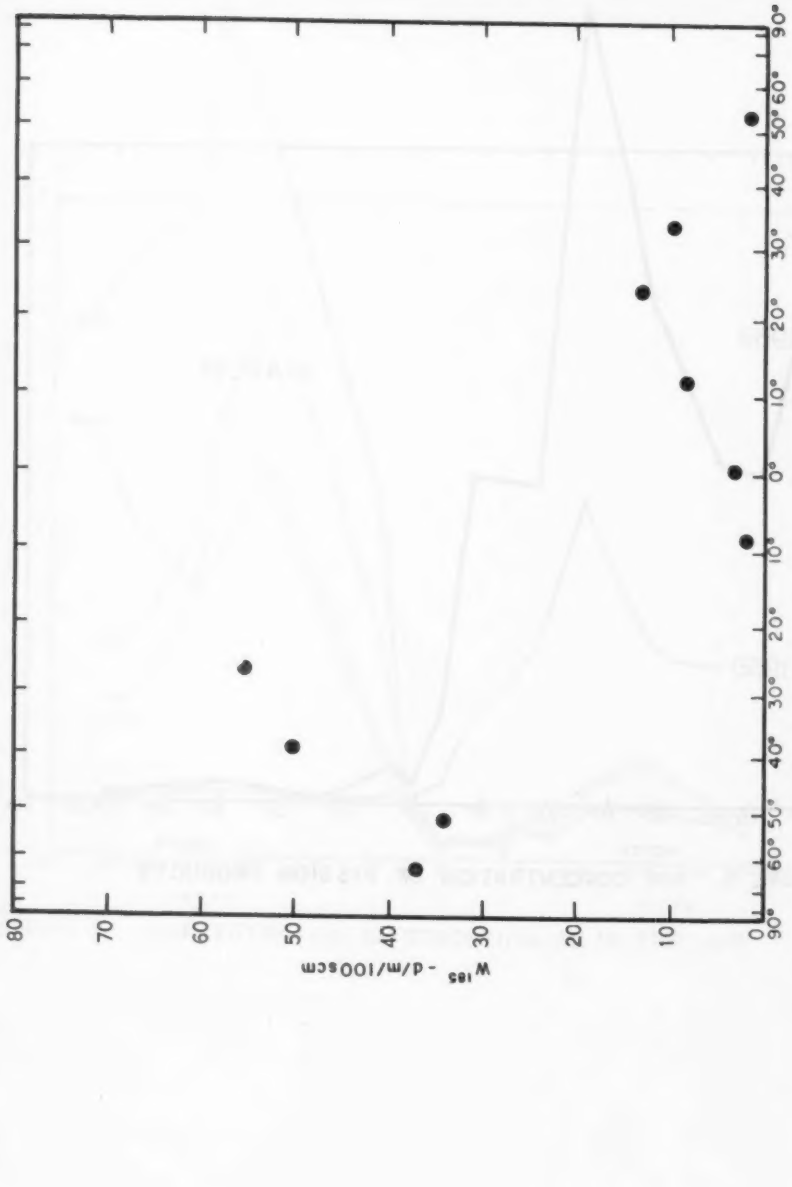
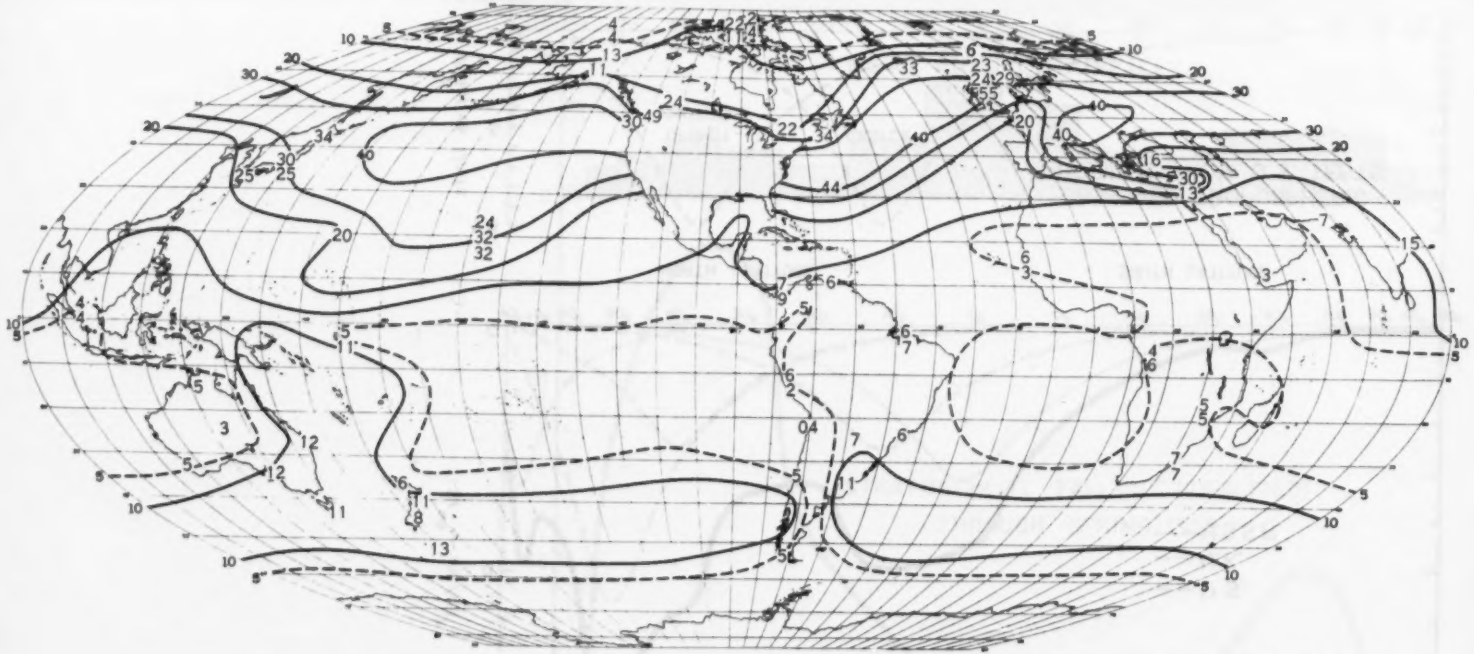


FIGURE 10 TUNGSTEN-185 AIR CONCENTRATION, JANUARY, 1959

NORTH

SOUTH

FIGURE 10 TUNGSTEN-185 AIR CONCENTRATION, JANUARY, 1959



1958 SOIL DATA, Sr^{90} - mc / mi^2

FIGURE 11

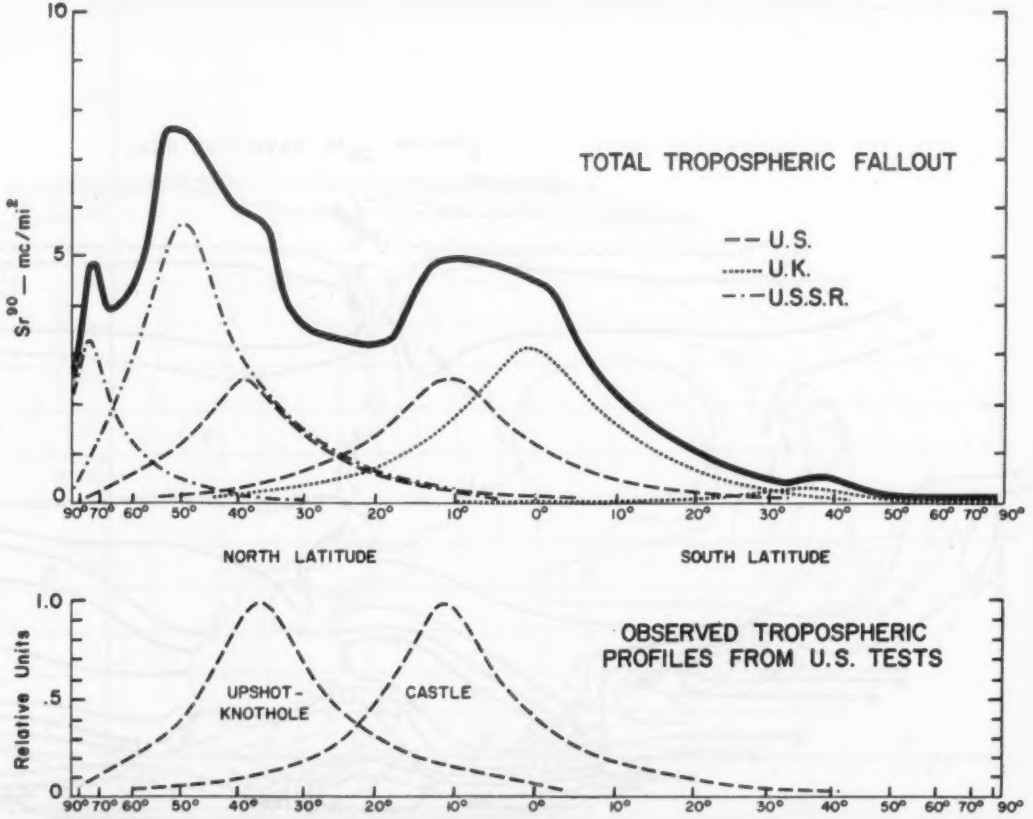

TOTAL TROPOSPHERIC FALLOUT
U.S.
U.K.
U.S.S.R.
Sr^{90} — mc/mi²
NORTH LATITUDE
SOUTH LATITUDE
OBSERVED TROPOSPHERIC PROFILES FROM U.S. TESTS
UPSHOT-KNOTHOLE
CASTLE
Relative Units

FIGURE 12

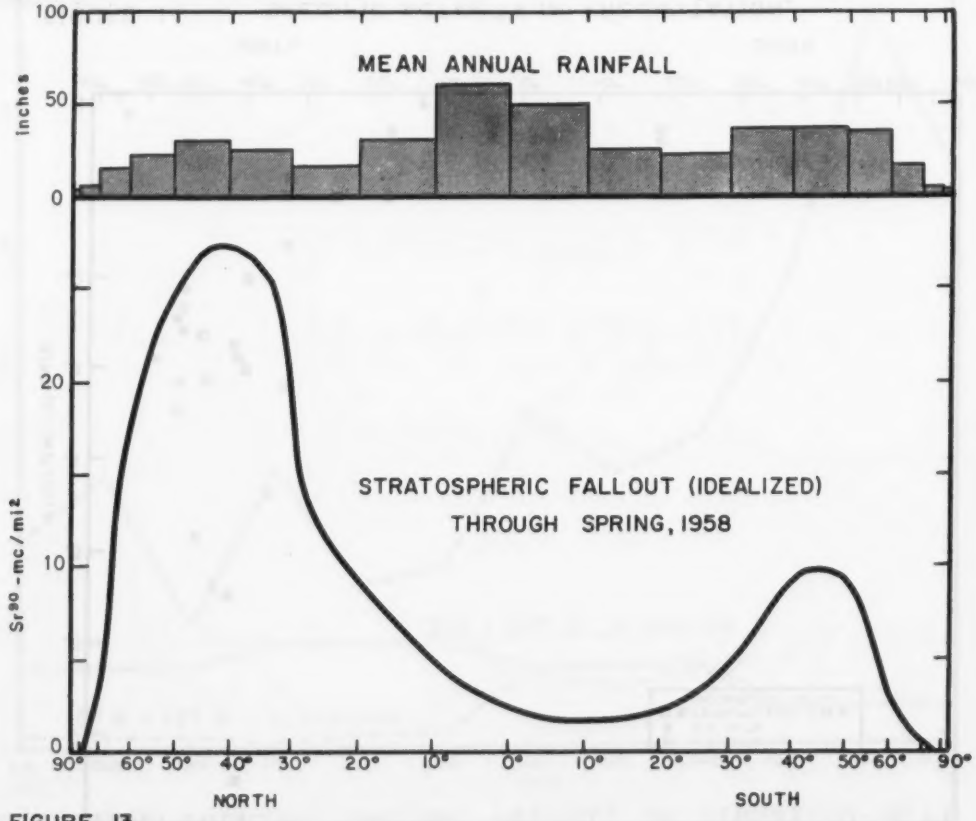

MEAN ANNUAL RAINFALL
inches
100
50
0
STRATOSPHERIC FALLOUT (IDEALIZED)
THROUGH SPRING, 1958
Sr90 - mc/mi2
20
10
0
90° 60° 50° 40° 30° 20° 10° 0° 10° 20° 30° 40° 50° 60° 90°
NORTH
SOUTH

FIGURE 13

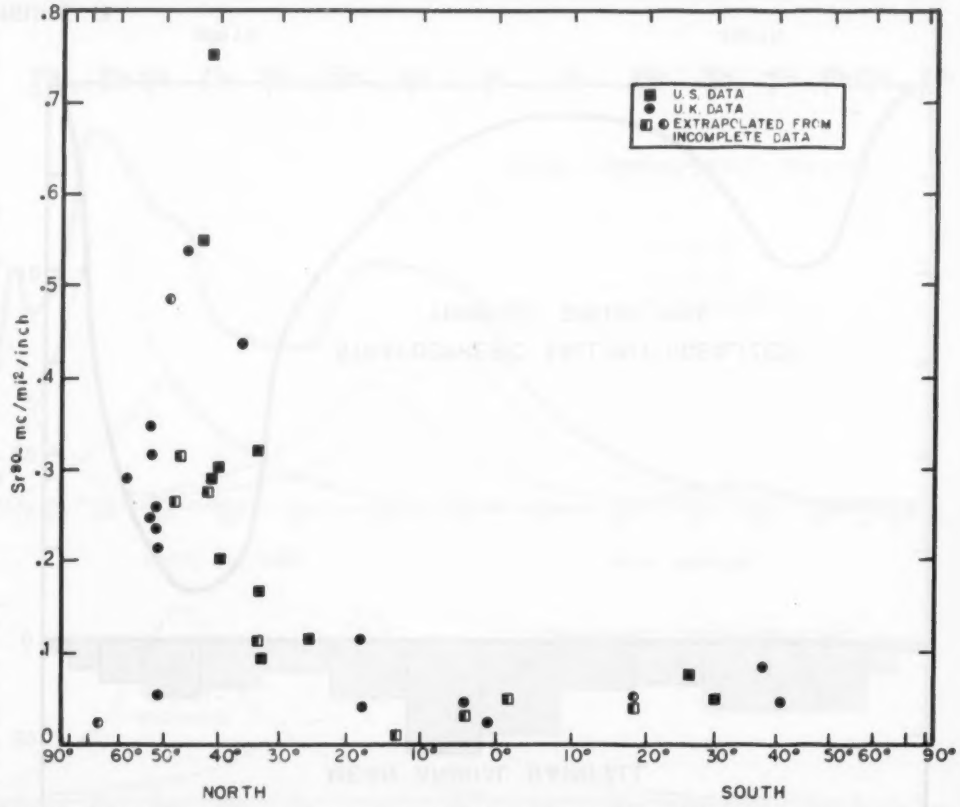


FIGURE 14 SPECIFIC ACTIVITY IN PRECIPITATION, JULY 1957 - JUNE 1958

FIGURE 14 SPECIFIC ACTIVITY IN PRECIPITATION, JULY 1957 - JUNE 1958

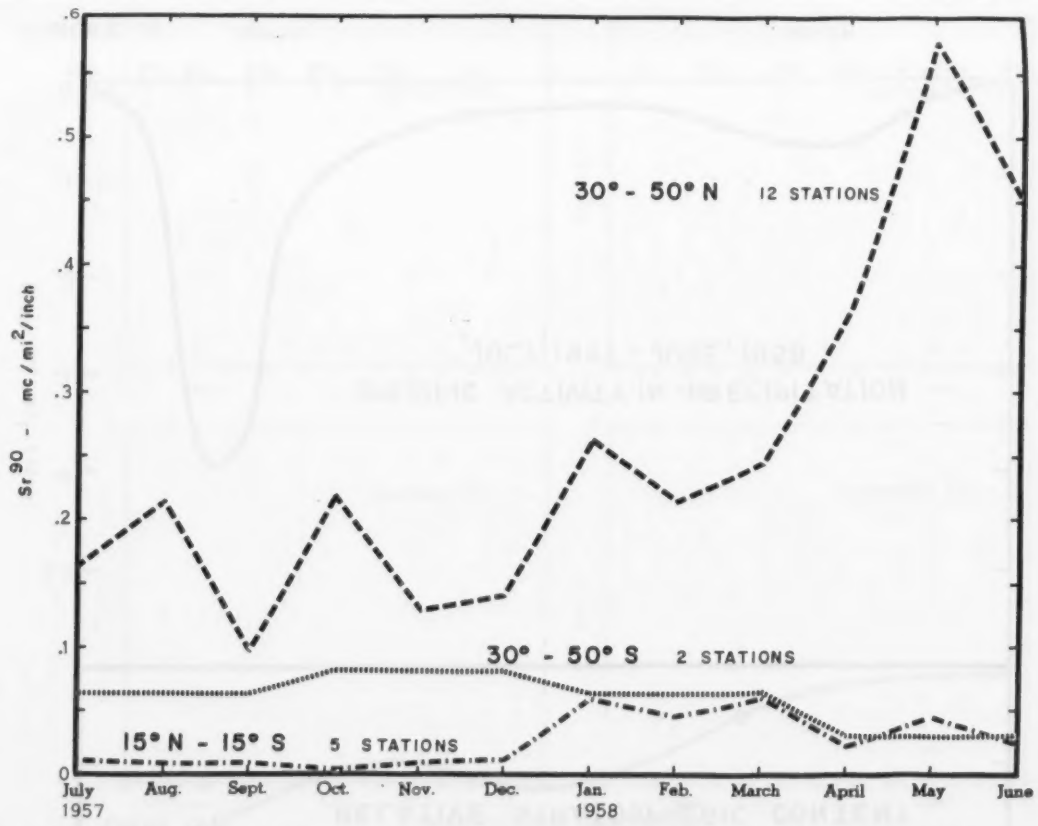


FIGURE 15 AVERAGE MONTHLY SPECIFIC ACTIVITY OF STRONTIUM-90

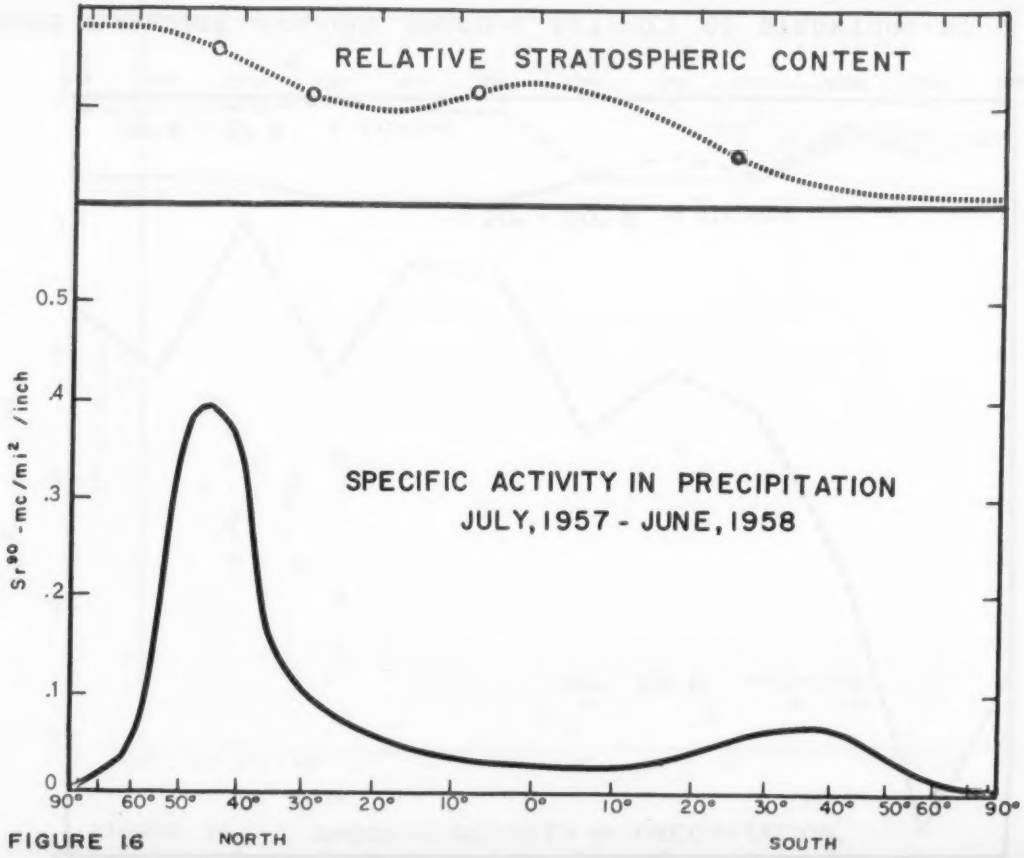

RELATIVE STRATOSPHERIC CONTENT
SPECIFIC ACTIVITY IN PRECIPITATION
JULY, 1957 - JUNE, 1958
Sr90 - mc/mi2 /inch
0.5
.4
.3
.2
.1
0
90° 60° 50° 40° 30° 20° 10° 0° 10° 20° 30° 40° 50° 60° 90°
NORTH
SOUTH

FIGURE 16

FIGURE 16 NORTH SOUTH

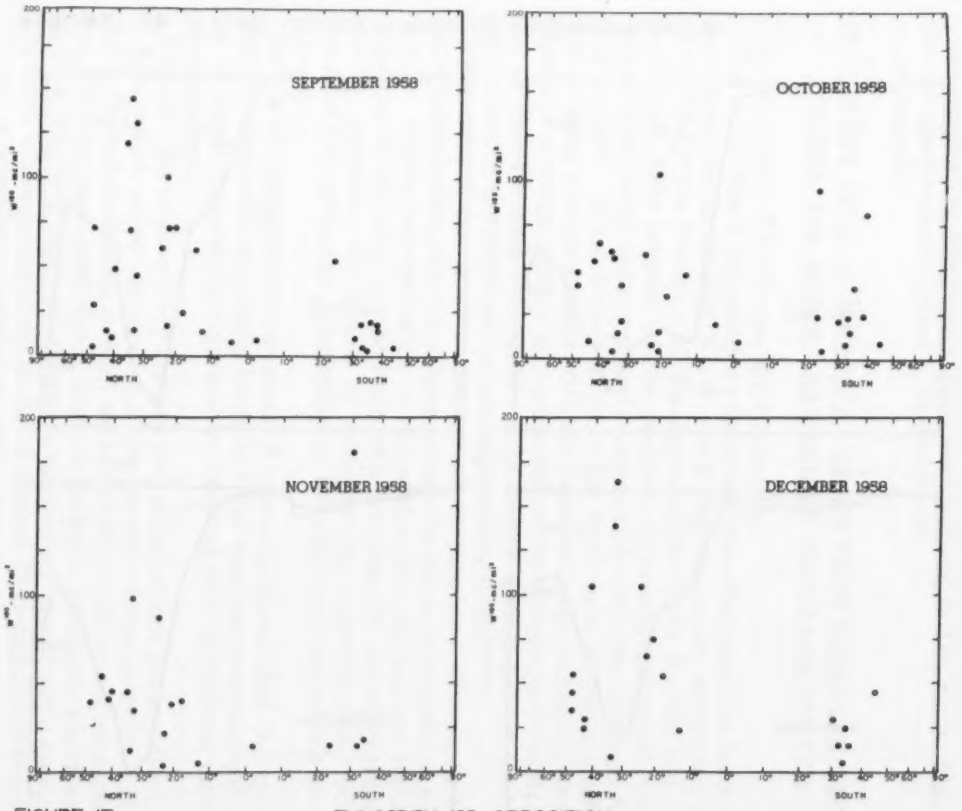


FIGURE 17 TUNGSTEN-185 DEPOSITION
(CORRECTED FOR DECAY TO JUNE 1, 1958)

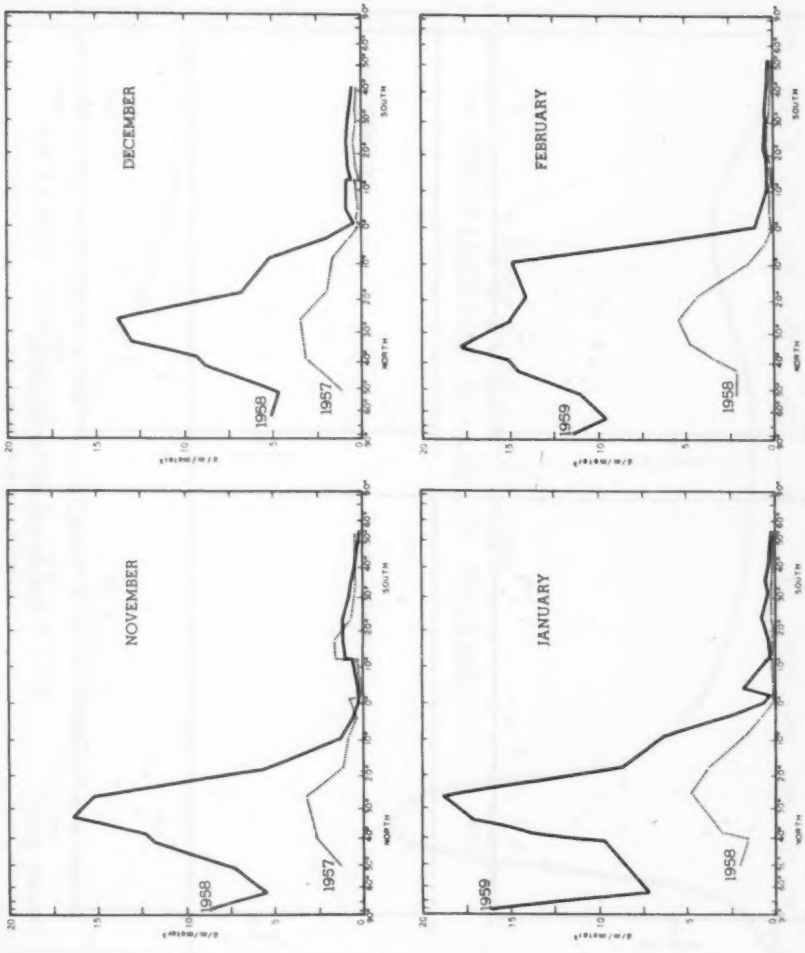


FIGURE 18 AIR CONCENTRATION OF FISSION PRODUCTS

Representative HOLIFIELD. Our next witness is Dr. E. A. Martell, Cambridge Research Center, U.S. Air Force.

Dr. Martell?

STATEMENT OF E. A. MARTELL,[1] GEOPHYSICS RESEARCH DIRECTORATE, AIR FORCE, CAMBRIDGE RESEARCH CENTER

Dr. MARTELL. Thank you, Mr. Chairman.

The work that I am going to describe this afternoon has been carried out at the Cambridge Air Force Research Center, supported substantially by the Division of Biology and Medicine for the last year and a half. My interest of the problem of interpretation of worldwide fallout stems from my early association with the Chicago Sunshine project. What I wish to do in the brief time I have this afternoon is to try to substantiate with the best available evidence, remarks I made in a recent article in science about the difference in contribution of Russian and U.S. tests in the heavy spring fallout and the high fallout in the north temperate latitude in general.

Since most of our fallout comes down in rains over the north temperate latitude belt, the rains there seem to be the most important place to look. Using isotope ratios in rains, the ratio of barium 140 and strontium 90 activity, or the ratio of strontium 89 and strontium 90 activity, provides the means of interpreting approximately which period of fallout is due principally to Russian tests and which to our own tests.

Before this suggestion was made it was considered that the spring fallout in the north temperate latitude band was due to some combination of small weapons testing and to seasonal and latitudinal mixing considerations.

I would like to show very quickly two slides which present the kind of data which allow us to decide the source of the activity. Here (fig. 1, formal statement, p. 832) we have barium 140 and strontium 90 data for the year 1958 from three locations: Southern California, our New England data, which makes up most of it, and some excellent data from Chicago obtained at the Argonne National Laboratory.

There is excellent correlation and agreement among these ratio data, showing that we can reliabily date from any one set of reliable determinations for one location the origin of the fallout which is occurring throughout the whole latitude band. We can reason from

FIGURE 18 AIR CONCENTRATION OF FISSION PRODUCTS

[1] Ph. D., radiochemistry, University of Chicago, 1950; program director, radiation effects and fallout studies, Armed Forces special weapons project, 1950 to 1954; director of Chicago sunshine project, Enrico Fermi Institute for Nuclear Studies, University of Chicago, 1954 to 1956; Chief, Nuclear Studies Branch, Atmospheric Circulations Laboratory, Geophysics Research Directorate, Air Force Cambridge Research Center, Bedford, Mass., August 1956 to present.

Fallout publications:

1. E. A. Martell, "Project Sunshire Bulletin No. 11; Strontium 90 Concentration Data for Biological Materials, Soils, Waters and Air Filters," AECD–3763, January 1957.
2. E. A. Martell, "The Chicago Sunshine Method; Absolute Assay of Strontium 90 in Biological Materials, Soils, Waters and Air Filters," AECU–3262, May 1956.
3. E. A. Martell, "Project Sunshine Bulletin No. 12; Strontium 90 Concentration Data for Biological Materials, Soils, Waters and Air Filters," AECU–3297 (rev.), January 1957.
4. E. A. Martell et al., "Natural Aerosols and Nuclear Debris Studies," Geophysics Research Note No. 8, Air Force Cambridge Research Center, 1958.
5. E. A. Martell, "Atmospheric Aspects of Strontium 90 Fallout," Science (in press).
6. E. A. Martell, statement "Global Fallout and Its Variability," hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, May 5, 1959.

data of this type that most of our fallout in the year 1958, nearly three-fourths of it, has come from Russian tests.

The second slide (fig. 2, formal testimony, p. 833) shows us quite a sharp difference. Using accepted methods of dating we find that at least 50 percent and perhaps nearly all of the fallout for the period from February through the strong peak in June, inclusive, is due to Russian tests. Then suddenly we have a factor of four decrease in concentration and for the following 3 months we are seeing debris almost exclusively from the Hardtack series. There is an important circulation feature, apparently, involved. One finds this sharp change almost every summer, indicating that following the very heavy fallout from Russian tests this spring we should experience a very sharp change in this trend, with low fallout in the late summer.

Representative HOLIFIELD. Before you leave that, the long line that goes to the right top of the picture, what does that represent?

Dr. MARTELL. The long line going up the right of the picture shows the accumulation of strontium 90 in the New England area for the year 1958. The total is approximately 20 millicuries per square mile, plus or minus one-half. The sharp curve showing a peak in June and low values in July, August, and September simply show the average concentration of rains. This would represent pretty well the average concentration at all locations in the north temperate latitude.

The next slide (fig. 4, formal testimony, p. 835), please. I took strontium 89 and strontium 90 ratio data to try to establish the origin of the fallout at north temperate latitudes for the whole period since early 1955. Most of our fallout has occurred over this period since the beginning of 1955. It is quite surprising that we find similar relationships which provide a reasonable basis of assigning the origin of fallout.

The next slide (fig. 5, formal testimony, p. 836), please. In this slide we have a summary of the rainfall concentration over the period since 1954. We can use the ratio data of the previous slides, to determine in which periods of rainfall we are dealing primarily with Russian fallout and in which we are dealing primarily with equatorial test debris.

Doing this we find a rather remarkable result. We are dealing with Russian fallout in the first half of 1955. We are dealing with it against the first half of 1956, a large portion of early 1967 and a large portion of early 1958. The activity is almost uniformly high. In the midsummer and early fall of each year we find a slight increase with time but the concentrations are quite low and are ascribable to either United Kingdom or United States tests near the Equator.

There is one feature that has not been described yet. In spite of these sharp changes these data have not been normalized for test yields. If we remember that the Redwing test series, corresponding to fallout in the second half of 1956, had about 3½ times the megaton contamination of the stratosphere as the October 1955 Soviet test series, which caused the fallout in the first half of 1956, then we must change the relative concentration ratio of Russian to Redwing test debris by that additional factor.

May I have the next slide (fig. 6, formal testimony, p. 837), please.

In order to normalize test yields, I took Dr. Libby's curve for the stratospheric inventory and assigned each increment, scaling each increment for the approximate amount of contamination injected into the stratosphere by the United States, the British, or the Soviet test that was involved. I tabulated the actual numbers in my formal testimony.

Using these numbers, I was able to normalize the data of the last slide. Taking only the three test series where there were no differences in analytical techniques and no differences in location, it is possible to make a quite reasonable assignment of relative concentration of fallout per megaton of fission for different types of tests.

The next slide (fig. 7, formal testimony, p. 838), please. The result is rather remarkable. We find that the 1955 Soviet tests, per megaton of stratospheric contamination, gave us 10 times the concentration at north temperate latitude regions as we got from the Redwing test. This latter surprisingly, is an additional six times the average we got from the Castle test. The Castle test represented the most substantial yields of U.S. test production history.

These differences (fig. 7), of course, represent relative fallout rates, not total fallout. The differences are not as marked as this if you integrate and are concerned with total strontium 90 accumulation. However, there are other differences. The Russian debris, because it comes down fast, is confined to the hemisphere. Perhaps it is deposited more selectively in latitude.

One can check the summary of injection yield (fig. 6) versus the summary of total production yields that were passed out this morning and find that apparently, most of the Soviet debris was emitted in air bursts. So, if we compare the test history we find roughly five times as much contamination per megaton of Russian tests at north temperate latitudes as we do for equatorial tests.

There are one or two reservations about this number. It is possible that there is a seasonal effect which is masked. We may be in error by as much as a factor of 2 in the assignment of the debris as being from the last Russian test series or from the last U.S. test series. It may be that we must reduce the relative significance of Russian and U.S. tests by at most a factor of 2.

There are many other consequences of the differences in test rate, all being more serious for debris which comes down faster at these very high concentrations. It means that we should perhaps take another look at the significance of the shorter lived gamma ray emitters associated with Russian fallout. We might expect, because we are dealing with 10 times the concentration per megaton at these latitudes, that depending on what circulation or weather anomolies we are dealing with, we may suffer very heavy fallout in limited areas and produce extensive hot spots. I think this is more likely to produce serious hot spots than a series of small weapons tests in Nevada.

I think my time is up. Most of the other things that I can conclude from the data I analyzed are presented in my formal testimony.

Representative HOLIFIELD. Thank you, Dr. Martell.

Are there any questions of the doctor?

Your supporting material here is quite well worked out. It will be included in the record in its entirety.

(The supporting material referred to follows:)

GLOBAL FALLOUT AND ITS VARIABILITY

(Statement of E. A. Martell, Geophysics Research Directorate, Air Force Cambridge Research Center.)

I. Introduction.

The reliable interpretation of world-wide fallout has been severely limited by man's general lack of understanding of large-scale atmospheric circulation and mixing processes. The pace and variety of atomic testing have confused the interpretation of fallout evidence. There has been perhaps too much emphasis on quantity rather than quality of data collected in the documentation of world-wide fallout. In order to render the complex subject of world-wide fallout manageable it has been necessary to make numerous simplifying assumptions and approximations in the treatment and the interpretation of fallout data. Considering how little is known of the stratospheric transport of nuclear bomb debris, stratospheric storage times estimated for one series or period of atomic tests cannot be applied with confidence to atomic tests of widely different nature. Evidence for substantial variation in stratospheric storage times, tropopause transport paths, and final surface distribution areas for various high yield atomic tests is presented and discussed below.

In a recent paper (1), I reviewed some of the atmospheric aspects of fallout and briefly discussed the several alternative interpretations of strontium-90 fallout which have been proposed by Libby (2-4), Stewart (5)

and Machta (6, 7). There was disagreement in explanation for two important features of northern hemisphere fallout. The periodic large increase in Sr^{90} fallout rate, usually in the spring, and the intense band of fallout at north temperate latitudes had been attributed to tropospheric fallout by Libby and to seasonal and latitudinal selectivity in downward mixing of old stratospheric debris by Stewart and Machta. I presented the alternative view that each major increase in Sr^{90} fallout rate at north temperate latitudes was due to fresh stratospheric debris from the immediately preceding Soviet atomic tests. My conclusions about global fallout at that time may be briefly summarized as follows:

(1) That tropospheric contamination from small weapons tests is a minor factor in world-wide fallout.

(2) That stratospheric contamination from Soviet tests is selectively deposited at north temperate latitudes in less than one year.

(3) That stratospheric contamination from equatorial tests exhibits storage times of 5 to 10 years and is distributed approximately uniformly world-wide.

(4) That seasonal effects are to be assigned only a secondary role in the explanation of major variations in fallout rate.

Additional evidence to support these views is presented below, together with discussion of evidence for the altitude dependence of stratospheric storage time and mention of other meteorological variables which

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affect the interpretation of global fallout. The relative contribution of the United States and Soviet tests to the intense band of fallout at north temperate latitudes and the external gamma radiation dosage from fallout in this region are estimated.

II. Interpretation of Ba^{140} and Sr^{90} Activity Data for 1958 Bedford Rainfall.

The Ba^{140} and Sr^{90} activity ratios for 1958 Bedford rains are presented in Fig. 1. Methods of sampling and analysis have been described elsewhere (8, 9). Similar data obtained for spring 1958 rains at Lemont, Illinois (10) and La Jolla, California (11) are included for comparison. For the Bedford data the probable error in isotope ratio, based on all sources of error in analysis of Ba^{140} and Sr^{90} activities, is indicated in Fig. 1. Activity ratio data with probable error greater than 10 percent are limited to a few very light rains which provided samples of less than one-tenth liter volume and to samples of negligible Ba^{140} activity.

It is usually assumed (2-7) that short-lived fission product activity observed in rainfall and surface air is tropospheric contamination from small weapons tests and is washed-out by rains with a half-time of removal of about 30 days (5). On this basis only a negligible fraction of 1958 Sr^{90} fallout at Bedford, Fig. 2, can be associated with the observed Ba^{140} activity.

However there are several features in the data which support the viewpoint that the 12.8 day Ba^{140} activity is stratospheric in origin. A persuasive argument can be based on the data for the period April 10 to the end of May. During this period the Ba^{140}/Sr^{90} activity ratio decreases linearly with the decay rate of Ba^{140}. Since the average monthly Sr^{90} concentration in rains and the Sr^{90} deposition rate, Fig. 2, are increasing over this period, the Ba^{140} activity must be stratospheric in origin. For tropospheric Ba^{140} activity and with Sr^{90} known to be predominantly stratospheric in origin, the Ba^{140}/Sr^{90} ratio should decrease due to diffusion and washout of Ba^{140} as well as to Ba^{140} decay. The stratospheric origin of the Ba^{140} activity can also be argued on the basis of both the magnitude of the Ba^{140}/Sr^{90} activity ratios and the gradual and systematic change in ratios with time. A mixture of tropospheric Ba^{140} activity and stratospheric Sr^{90} activity should give rise to large and random fluctuations in activity ratios.

The Ba^{140}/Sr^{90} activity ratio data, Fig. 1, for the period July through September 1958 appeared to indicate two discrete stratospheric sources: one with debris from an early portion of the United States HARDTACK atomic test series and the other with fresher debris produced at least three weeks later. This possibility was explored by plotting the mean trajectories at 14,000 feet for air associated with each rain during the period. Without exception, the trajectory data, Fig. 3, indicated a polar air source for rains of group A, Fig. 1, and a tropical air source for

group B, Fig. 1, rains. The persistence of the distinction indicates slow mixing between polar and tropical air in the troposphere. It is evident that at least that portion of Operation HARDTACK debris which comes down in polar air follows a stratospheric path.

The existence of two distinct paths for downward mixing of stratospheric debris complicates the interpretation of global fallout. For example, the fallout pattern for the early HARDTACK debris which mixed into polar air will differ from that for the later HARDTACK debris which did not. It is apparent that the concentration and isotope ratio data for fission products (and for cosmic ray produced activities) in tropospheric air and in rainfall must be classified with respect to mixing history before reasonable interpretation can be made. Thus the June data, Fig. 1, can be explained in terms of (a) an initial rise due to HARDTACK Ba^{140} activity in tropical air, (b) a sharp drop in Ba^{140} activity during mid-June due to a transition to polar air, and (c) subsequent rise due to appearance of HARDTACK Ba^{140} activity in polar air.

The period of Ba^{140} production can be identified for each peak or portion of the Ba^{140}/Sr^{90} activity ratio curve, Fig. 1, by extrapolation along a Ba^{140} decay slope line to the production ratio, taken as 1200. Thus the test series source and, for well spaced high yield tests, the individual shot source for the Ba^{140} activity can be identified. The Sr^{90} activity associated with identified events can be estimated within a factor of two or better. On this basis it can be seen that 1958 Sr^{90} fallout at Bedford and

other areas of similar latitude was dominated by contamination from Soviet tests except during July, August and September. During these 3 months, HARDTACK was the prominent test source and average monthly precipitation concentrations were the lowest observed during the year except for the month of January.

III. Interpretation of Sr^{89} and Sr^{90} Activity Data for North Temperate Latitude Rainfall, 1955-1958.

The ratios of Sr^{89} and Sr^{90} activity in precipitation at Harwell, England (5), Lemont, Illinois (10) and New York City (12) covering the period since early 1955 are presented in Fig. 4. These ratios should be reasonably representative for other north temperate latitude locations at corresponding times. For each period during which the Sr^{89}/Sr^{90} activity ratio apparently decreases in accordance with the 54-day half-life of the Sr^{89} activity, the ratio data are extrapolated to the approximate production ratio, taken as 170. The source of most of the Sr^{89} activity and a substantial percentage of the Sr^{90} activity is the major test series at or immediately following the intercept date. The nuclear test information noted across the top of Fig. 4 are taken from an unclassified summary (12) of announced nuclear tests compiled by the U. S. Weather Bureau.

It is remarkable how well most of the activity ratio data from early 1955 through 1957 can be fitted by the above scheme of analysis. It is apparent that the fall 1955 Soviet tests and the spring 1956 REDWING

tests were the prominent contributors to fallout for the first half and second half of 1956 respectively. It is also indicated that the fall 1954 Soviet tests, usually regarded as of little consequence, made significant contribution to fallout at northern latitudes during much of the year 1955. This surprising result becomes more plausible when differences in mixing history for equatorial and high latitude test debris are considered (see below).

The Sr^{90} activity concentration data (5, 8, 12, 13) for precipitation at north temperate latitudes, averaged for periods from 2 weeks to one month and covering the whole history of fallout since early 1954, are presented in Fig. 5. The dominant test source of the fallout, based on Sr^{89}/Sr^{90} ratio data of Fig. 4 and on Ba^{140}/Sr^{90} ratio data of Fig. 1, is indicated for various periods of precipitation in Fig. 5. The result of this classification of precipitation data is most striking. All high concentration data is attributed to Soviet tests. Rains in which equatorial tests are the most prominent source are uniformly low in Sr^{90} activity.

IV. Origin of North Temperate Latitude Fallout.

Various atomic test series have differed widely with respect to the amount of fission contamination injected into the stratosphere. A summary of the stratospheric inventory of Sr^{90} has been furnished by Libby (14) and is reproduced in Fig. 6. Each major test series and its stratospheric Sr^{90} contribution estimated from Fig. 6 is listed in Table 1.

TABLE 1: Approximate Stratospheric Contamination[a] from Major Atomic Tests.

Test Series	Date	Location	MT of Fission[b]
IVY	November 1952	11°N	1.4
CASTLE	Spring 1954	11°N	20
U.S.S.R.	Fall 1954	52°N	--
U.S.S.R.	Fall 1955	52°N	1.8
REDWING	Spring 1956	11°N	6.7
U.S.S.R.	Fall 1956	52°N	2.7
U.S.S.R. U.K.	Spring 1957 Spring 1957	52°N 2°N	2.7
U.S.S.R.	Fall 1957	52°N	4.5
U.S.S.R.	Early 1958	52° + 73°N	3.3
HARDTACK	Spring 1958	11°N	4.0
U.S.S.R.	October 1958	73°N	20.0[c]
		Total	~ 67

a. Amount retained in stratosphere: 20% of production for surface coral shots, 80% for surface seawater shots, and 100% for air shots. (4, 14)

b. Scaled from Fig. 6, Reference 14.

c. In a more recent report, Libby indicates 12.5 to 15 MT for the October 1958 Soviet tests.

The precipitation data in Fig. 5 together with the yield data in Table 1 make possible the estimation of the relative concentration of north temperate latitude rains per megaton of stratospheric contamination from various tests. Such comparison is made for the CASTLE, REDWING and 1955 Soviet tests in Fig. 7. Each data point in Fig. 7 represents the concentration of rainfall from Fig. 5 divided by the stratospheric contamination in MT for each respective test. Comparison of the REDWING and the 1955 Soviet tests, Fig. 7, was made assuming no Sr^{90} contribution from earlier tests. If a constant background of Sr^{90} from earlier tests is assumed, the difference between the REDWING and 1955 Soviet tests is enhanced. There appears to be no justification for assuming high contribution of earlier Sr^{90} production only in the presence of debris from Soviet tests. Even if this extreme assumption were made, the Sr^{89}/Sr^{90} activity ratio data, Fig. 4, should limit its influence on test differences to a factor of 2 or less.

The comparison of tests, Fig. 7, was limited to the three chosen because these could be compared using precipitation concentration data, Fig. 5, and isotope ratio data, Fig. 4, for a single location and laboratory, thus avoiding differences due to methods of collection and analysis and to geographical factors. The spacing of high yield tests before 1957 also allows for better discrimination of test source on the basis of Sr^{89}/Sr^{90} activity ratios. Inspection of the concentration data for other tests, Fig. 5, and the corresponding stratospheric contamination contributions, Table 1, indicates that the comparison

for the REDWING and 1955 Soviet tests holds reasonably well for other equatorial and Soviet tests. When we consider that the concentration of rains at north temperate latitudes following Soviet tests has been nearly 60 times that following the CASTLE tests per unit of stratospheric contamination, it becomes understandable that the fall 1954 Soviet tests could contribute significantly to 1955 fallout as indicated in Fig. 4 and still be ignored in the inventory of tests, Fig. 6 and Table 1.

The factor of ten difference between the REDWING test and the 1955 Soviet test, Fig. 5, is explainable on the basis of distribution area and stratospheric storage time. The additional factor of about 6 in the relative contribution of the CASTLE and the REDWING tests may be accounted for best on the basis of longer stratospheric storage times associated with greater cloud height for the CASTLE test contamination. Stratospheric storage times of about 6 months to 1 year for Soviet tests, 1 to 2 years for equatorial contamination from tests typified by REDWING and 5 to 10 years for the CASTLE test appear to be consistent with the above and other (1-4, 14) observations.

Assuming that north temperate latitudes ultimately receive about 5 times as much Sr^{90} fallout per megaton of Soviet tests as for equatorial tests and further assuming that at the end of 1958 all Sr^{90} activity was deposited except for one-half of CASTLE and HARDTACK and all of the October 1958 Soviet test production, it is estimated that about 75 percent

of the Sr^{90} already deposited at these latitudes comes from Soviet tests. After the balance in the stratosphere has come down and assuming no further atmospheric contamination from additional tests, the final total at north temperate latitudes will be a little more than double the late 1958 levels and about five-sixths of the total will have come from Soviet tests.

V. Discussion of Rainfall Concentration Data.

The rainfall concentration data, Fig. 4, averaged for precipitation collected during periods of from 2 weeks to one month, were assumed to provide a reasonable measure of fallout rate. The good agreement between the Chicago and Milford Haven data from April 1954 to the end of 1955 is reassuring. However it would be very useful if we had a reliable relationship for the variation of Sr^{90} in rains with type or amount of rainfall so that individual rains can be compared and so that the concentration of Sr^{90} in rains not measured can be estimated. Selecting data for determining such relationship has been complicated by the ever-changing source strength and distribution for the fission products as well as by meteorological variability. It was also observed, Fig. 1, that the isotope concentration and the isotope ratio may differ sharply in polar and tropical air and in the rainfall associated with them. This further complicates the interpretation of individual rain concentration data or of average concentration data per month or per inch of precipitation.

In Fig. 8, the Sr^{90} activity concentration data for individual Bedford rains are plotted against amount of rainfall. The data were taken for two

periods of two months which were relatively free of violent changes in Sr^{90} concentration and in Ba^{140}/Sr^{90} activity ratio (see Fig. 1). The two fitted curves, one for April-May 1958 and the other for July-August 1958 are similar to that observed (5) for Harwell, England, rains. A typical curve for natural tropospheric aerosols is included in Fig. 8 for comparison. The Sr^{90} concentration becomes nearly constant for medium to heavy rains, apparently because it is continually replenished with Sr^{90} present at higher concentrations in the upper troposphere, or even the lower stratosphere. Contrastingly the natural aerosols, which decrease in concentration with altitude, show continually decreasing rainfall concentration with increasing rainfall amount.

On close inspection it became apparent that nearly all the April 1958 rains which carried fresh Soviet test debris were associated with heavy rains, whereas rains during May were more varied. Amuch sharper separation into light and heavy rains is indicated for the July-August 1958 data which have been classified according to polar or tropical origin of the air at cloud level.

It has been noted that air trajectory data are essential to the interpretation of the Ba^{140}/Sr^{90} activity ratio data, Fig. 1. Meteorological interpretation must also be found for other features of the data such as the striking increase and decrease in precipitation concentration, Fig. 5, associated with the appearance and disappearance of each period of heavy fallout from Soviet tests. Particularly striking is the drastic shift,

illustrated in Fig. 2 during June and July, from high concentration of Sr^{90} from Soviet tests to low Sr^{90} from equatorial tests. A serious shift in circulation pattern must be involved.

The above discussion illustrates some of the variability of rainfall data and the complexity of the problem of interpreting or correlating such data. If we continue to look only at trends or averages and do not obtain a detailed understanding of the meteorology and geophysics involved in global fallout, we will not be able to predict or evaluate fallout with a reasonable degree of confidence.

VI. External Gamma Radiation Dosage from 1957-1958 Fallout at North Temperate Latitudes.

The reduced stratospheric storage time and the selective north temperate latitude zone of deposition for Soviet test debris is perhaps of more consequence from the standpoint of external gamma radiation than of Sr^{90} fallout. With the possible exception of extreme altitude detonations, stratospheric storage times appear to be short compared to the half-life of Sr^{90} activity. Thus the integrated Sr^{90} fallout from various tests will differ only in relation to fission yield and distribution area. The north temperate latitudes will receive about 5 times as much Sr^{90} per megaton of Soviet testing as they will per megaton of equatorial testing. On the other hand differences in external gamma radiation contribution from various tests are approximately reflected by the relative Sr^{90} fallout rate data, Fig. 7.

Although the external gamma radiation contribution of fallout has not been well documented, sufficient information is available to allow approximate estimation of the gamma radiation dosage from fallout during 1957 and 1958. Cumulative Ba^{140}-La^{140} fallout at Bedford, Massachusetts for the last 9 months of 1958 is presented in Fig. 9. The average surface distribution over this period is 31 millicuries per square mile, with a peak monthly average of 90 millicuries per square mile in November 1958. The corresponding dose rates, estimated by the approximate method of Dunning (15), are 4.4 mr/year for the average over the 9-month period and 12.8 mr/year for the peak rate in November 1958. The dose rate due to Ba^{140}-La^{140} activity in Lemont, Illinois soils during October 1957 has been estimated as 1.0 to 1.5 mr/year.

If the pace of testing and fallout is sufficient to maintain an average of 31 millicuries of the short-lived (12.8 day) Ba^{140}-La^{140} activities per square mile, other gamma-ray emitting fission products of longer half-life will accumulate in soils. Evidence for such accumulation is indicated in the 1957 soil data of Gustafson et al (16, 17) which is presented below in Table 2.

TABLE 2: Fission Product Activity on the Ground at Argonne National Laboratory.

Isotope	Half-Life	May 1957 (mc/mi^2)	July 1957 (mc/mi^2)	October 1957 (mc/mi^2)
Zr^{95}-Nb^{95}	65d	180	195	230
Cs^{137}	27y	35	34	37
Ru^{106}-Rh^{106}	1.0y	175	180	180
Ru^{103}	39.8d	175	200	240
Ce^{144}-Pr^{144}	285d	240	260	275

The dose rates in milliroentgens per year corresponding to each of the soil activity values in Table 2 are given in Table 3. Estimates were made using the method of Dunning (15) for the approximate dose rate 3 feet above an infinite,

TABLE 3: External Gamma Radiation Dose Rates Corresponding to 1957 Lemont, Illinois Soil Activity Data.

Isotope	May 1957 (mr/year)	July 1957 (mr/year)	October 1957 (mr/year)
Zr^{95}-Nb^{95}	13.8	14.9	17.6
Cs^{137}	1.08	1.05	1.14
Ru^{106}-Rh^{106}	3.42	3.52	3.52
Ru^{103}	4.75	5.43	6.51
Ce^{144}-Pr^{144}	0.79	0.85	0.90
TOTAL	23.84	25.75	29.67

uniformly contaminated plane. The total dose rates indicated will be increased somewhat due to contribution from Ba^{140}-La^{140}, Ce^{141} and other gamma ray emitting bomb products.

The total dose rate estimated for October 1957 is equal to about 1/3 of the total natural background radiation from external sources which has been reported (18) as about 30 millirem per year from cosmic rays and 60 millirem per year from local gamma radiation due to uranium, thorium and potassium in surface materials.

Considering the observed increases in Ba^{140}-La^{140} activity between October 1957 (10) and the end of 1958 (Fig. 9), the accumulation of longer-lived gamma ray emitters in the soil and differences in fallout levels for other areas compared to Lemont, Illinois, it is indicated that some areas at north temperate latitudes have experienced external gamma radiation exposure during 1958 of as much as 50 percent or more of the annual natural background radiation exposure.

VII. Experiments in Progress.

Several experimental programs which are currently in progress should, by the end of 1959, furnish considerable insight on the differences in storage times, mixing paths and distribution areas for nuclear tests of various types. Two isotopes produced in the last U. S. Pacific tests, the 210-day half-life rhodium-102 activity representing high stratosphere equatorial debris and the 74-day half-life tungsten-185 activity representing low stratosphere equatorial debris, will be very useful as tracers to

describe global fallout for equatorial tests. In addition, the massive fission product contamination of the stratosphere at about 73°N from the October 1958 Soviet tests will provide graphic evidence for the behavior of debris from high latitude nuclear tests. The variation in air and precipitation concentration during the spring, summer, and fall of 1958, particularly for tungsten-185, Sr^{89} and Sr^{90}, will elucidate many of the circulation features and possible seasonal effects which have been obscured by the pace and variety of past testing. A continuation of the present cessation of nuclear tests for another year or two would increase the possibility of obtaining full benefit from the experiments now in progress.

Preliminary results for the rhodium-102 tracer experiment are limited to some observations by one of my associates, Dr. M. I. Kalkstein (19). He has measured low levels of Rh^{102} activity in air samples from the lower stratosphere of both hemispheres and in tropospheric air at Bedford, Massachusetts. Rh^{102} activity concentration data for samples already measured are not sufficiently high to be clearly distinguishable from the low background level of Rh^{102} produced in other nuclear detonations.

Documentation of the tungsten-185 activity and of the fallout from the October 1958 Soviet tests has not yet provided sufficient data to be very helpful in the interpretation of global fallout. There are preliminary indications from the recent Naval Research Laboratory air

concentration data (20) and from some measurements of Sr^{90} in recent rains collected at Washington, D.C. (21) and Bedford, Massachusetts, which tend to confirm the short residence time for Soviet atomic tests.

A series of important experiments is being carried out by another of my associates, Dr. C. E. Junge (22) who has developed techniques for determining the physical and chemical properties of stratospheric particles. Application of these techniques to the determination of the concentration distribution and the physical properties of particulate bomb debris in the stratosphere will make an important contribution to the evaluation of residence times and transport and scavenging mechanisms for global fallout.

VIII. Summary and Conclusions.

Interpretation of Ba^{140}/Sr^{90} and Sr^{89}/Sr^{90} activity ratio data provides strong support for earlier (1) suggestions that Soviet test debris experiences only a short hold-up time in the stratosphere and is selectively deposited at north temperate latitudes. Limited data on fallout from the October 1958 Soviet tests tend to support the same conclusion.

The Bedford rainfall data (Fig. 1) indicate different arrival times, concentrations and isotope ratios for fallout associated with polar and tropical air. This suggests two mixing paths for stratospheric debris across the tropopause: (a) general mixing downward into the polar troposphere at high latitudes and (b) downward mixing, presumably through the tropopause break, into the equatorial troposphere.

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Differences in relative fallout rates for the U.S. REDWING and CASTLE tests indicate substantially longer stratospheric residence time for CASTLE, presumably associated with greater average injection altitude for the stratospheric contamination.

It is concluded that the stratospheric storage time varies significantly with the altitude and the latitude of the initial stabilized clouds for atomic tests. Estimated residence times are 6 months to one year for Soviet tests, 1 to 2 years for equatorial tests in the lower stratosphere (typified by REDWING) and 5 to 10 years for the CASTLE test.

The distribution area of the fallout from various tests also appears to vary widely. Soviet test debris is preferentially deposited at north temperate latitudes. CASTLE debris, well mixed in the higher stratosphere, may be distributed approximately uniformly over the earth. The distribution of debris injected into the lower stratosphere near the equator is least predictable since it may partition non-uniformly between the two hemispheres and may also partition unevenly between polar and tropical air in a given hemisphere.

Total Sr^{90} fallout from Soviet tests will be about 5 times as high at north temperate latitudes per megaton of testing as that from equatorial tests.

The short residence time for Soviet tests leads to about an order of magnitude higher external gamma radiation intensity at northern latitudes compared with equatorial tests per megaton of fission. Data

for Bedford, Massachusetts rains and Lemont, Illinois rains and soils indicate that the 1957 and 1958 levels of fission products from Soviet tests gave rise to annual external gamma radiation exposures which may equal or exceed 50 percent of the external gamma radiation from natural sources in some areas at north temperate latitudes.

The author is deeply indebted to several associates, Drs. C. E. Junge, M. I. Kalkstein, P. J. Drevinsky and W. S. Hering, for numerous helpful suggestions. Dr. Drevinsky, with the assistance of Mrs. M. R. Weitzman and Miss N. A. Dimond, is responsible for the excellent Ba^{140} and Sr^{90} activity data for 1958 Bedford rains, Figures 1, 2 and 9.

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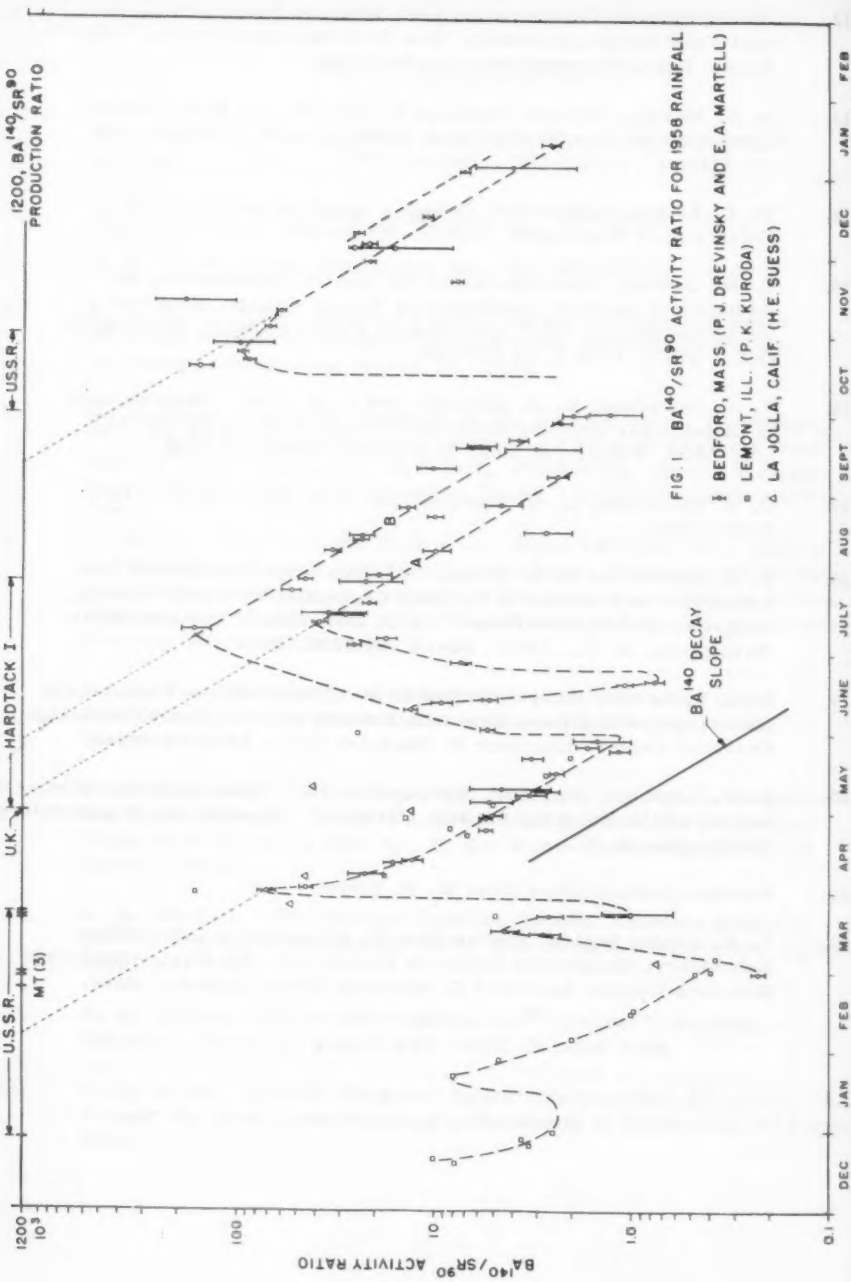


FIG. 1 BA^{140}/SR^{90} ACTIVITY RATIO FOR 1958 RAINFALL

‡ BEDFORD, MASS. (P. J. DREVINSKY AND E. A. MARTELL)

▫ LEMONT, ILL. (P. K. KURODA)

△ LA JOLLA, CALIF. (H. E. SUESS)

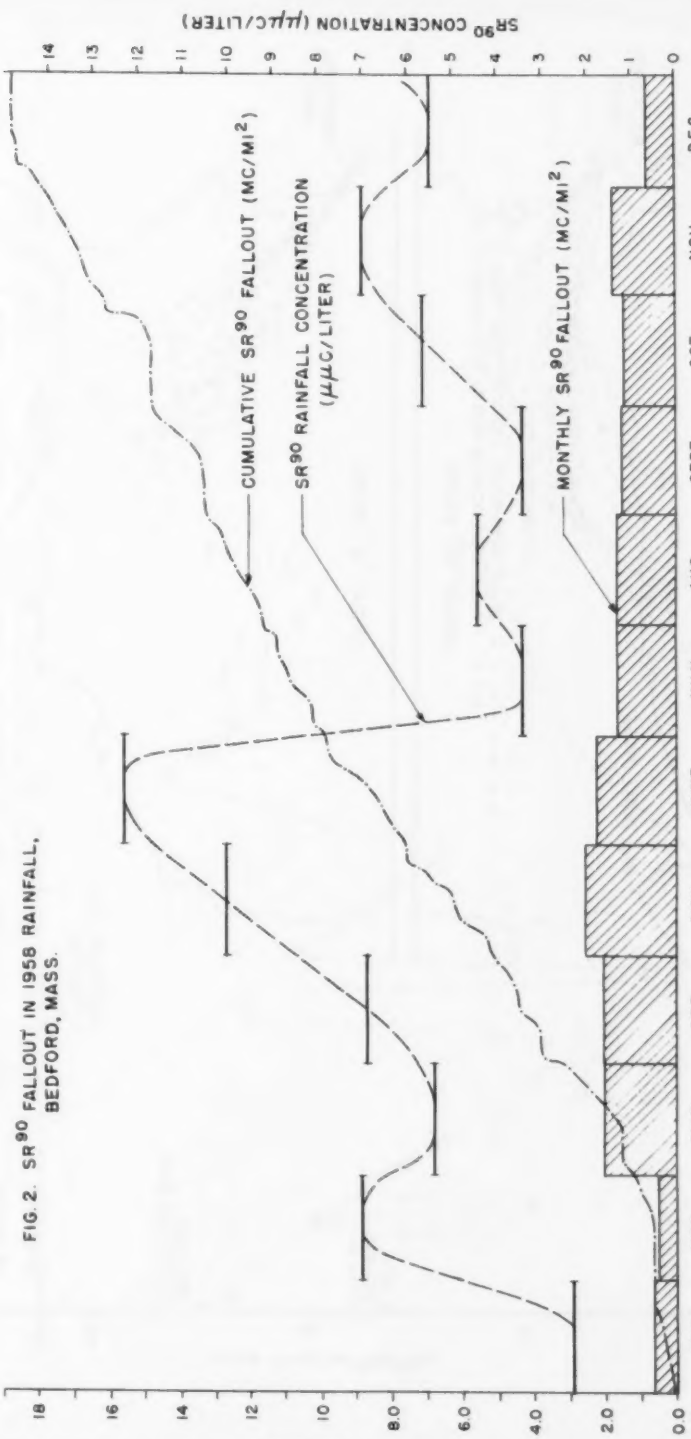

SR90 CONCENTRATION (μμC/LITER)
SR90 (MC/MI2)
CUMULATIVE SR90 FALLOUT (MC/MI2)
SR90 RAINFALL CONCENTRATION (μμC/LITER)
MONTHLY SR90 FALLOUT (MC/MI2)
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC

FIG. 2. SR^{90} FALLOUT IN 1958 RAINFALL, BEDFORD, MASS.

0.1 DEC 1957 JAN FEB MAR APR MAY JUNE 1958 JULY AUG SEPT OCT NOV DEC JAN 1959 FEB

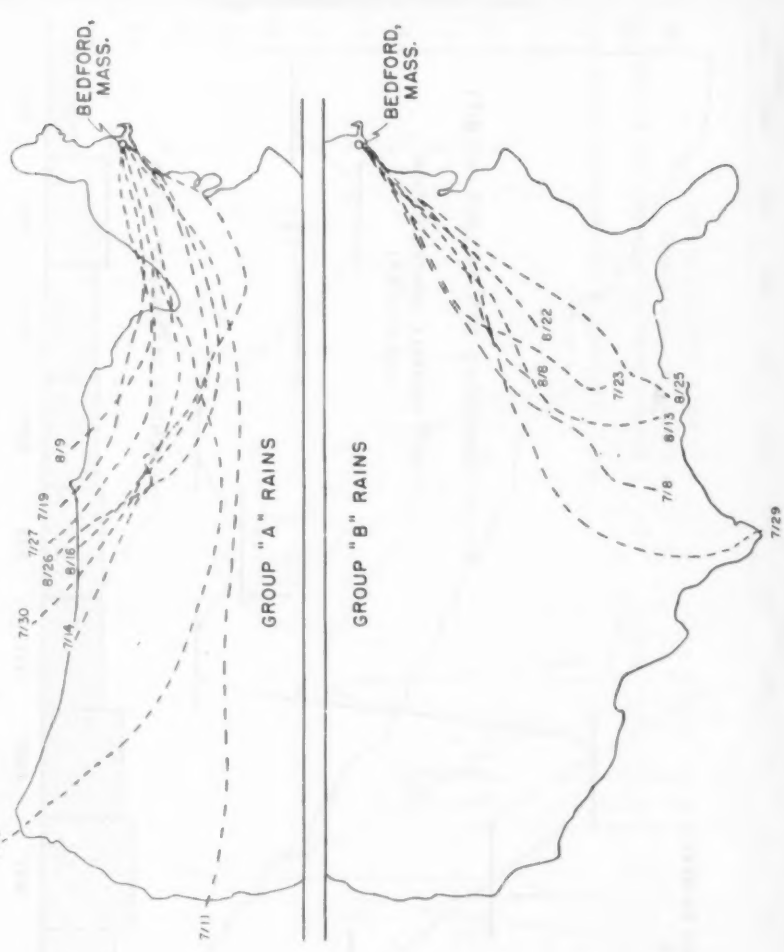


FIG. 3. MEAN HORIZONTAL TRAJECTORIES (14,000') FOR AIR ASSOCIATED WITH BEDFORD RAINS, JULY AND AUGUST, 1958

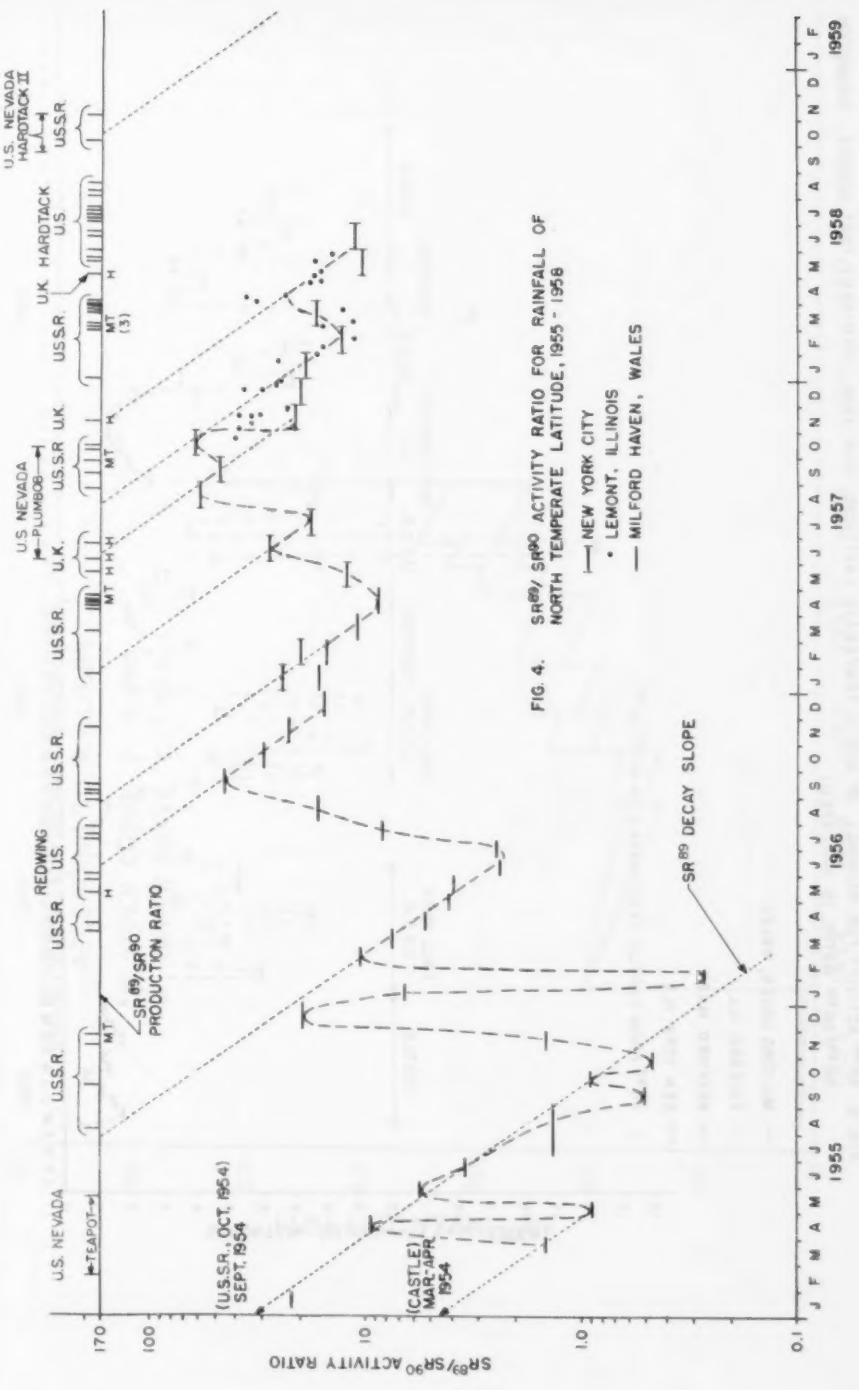


FIG. 4. SR^{89}/SR^{90} ACTIVITY RATIO FOR RAINFALL OF NORTH TEMPERATE LATITUDE, 1955 - 1958

— NEW YORK CITY
• LEMONT, ILLINOIS
— MILFORD HAVEN, WALES

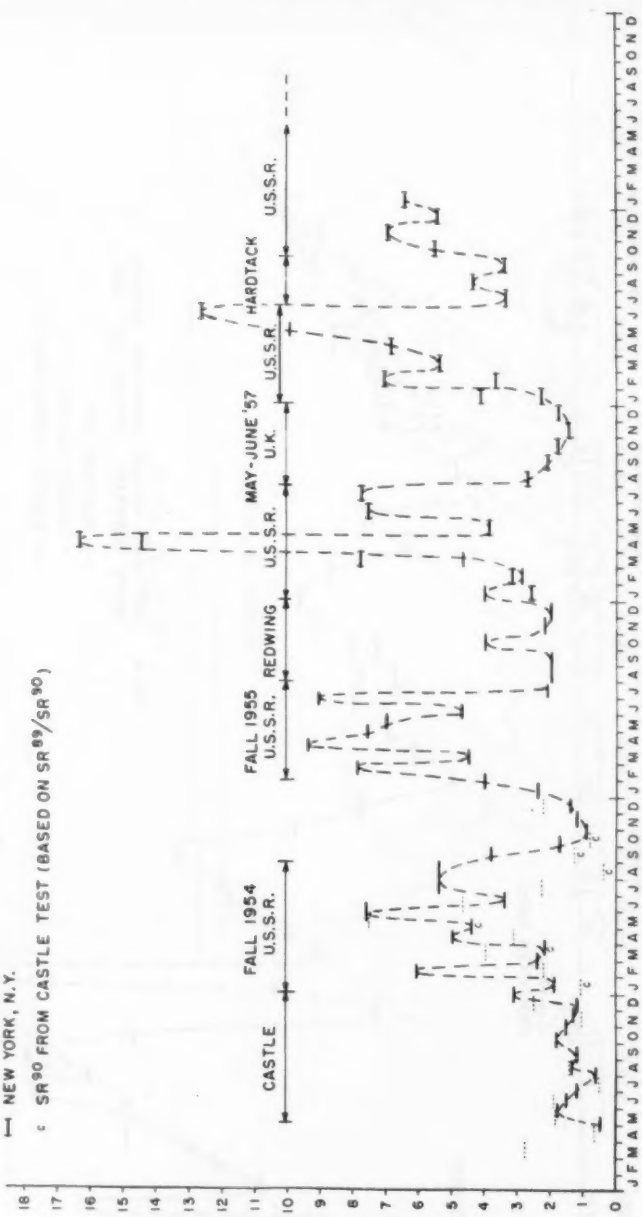


FIG. 5. SR^{90} ACTIVITY FOR RAINFALL OF NORTH TEMPERATE LATITUDE, 1954-1958 (DOMINANT TEST SOURCE, BASED ON SR^{89}/SR^{90} RATIO, IS INDICATED)

— MILFORD HAVEN, WALES
··· CHICAGO, ILL.
I BEDFORD, MASS.
I NEW YORK, N.Y.
c SR^{90} FROM CASTLE TEST (BASED ON SR^{89}/SR^{90})

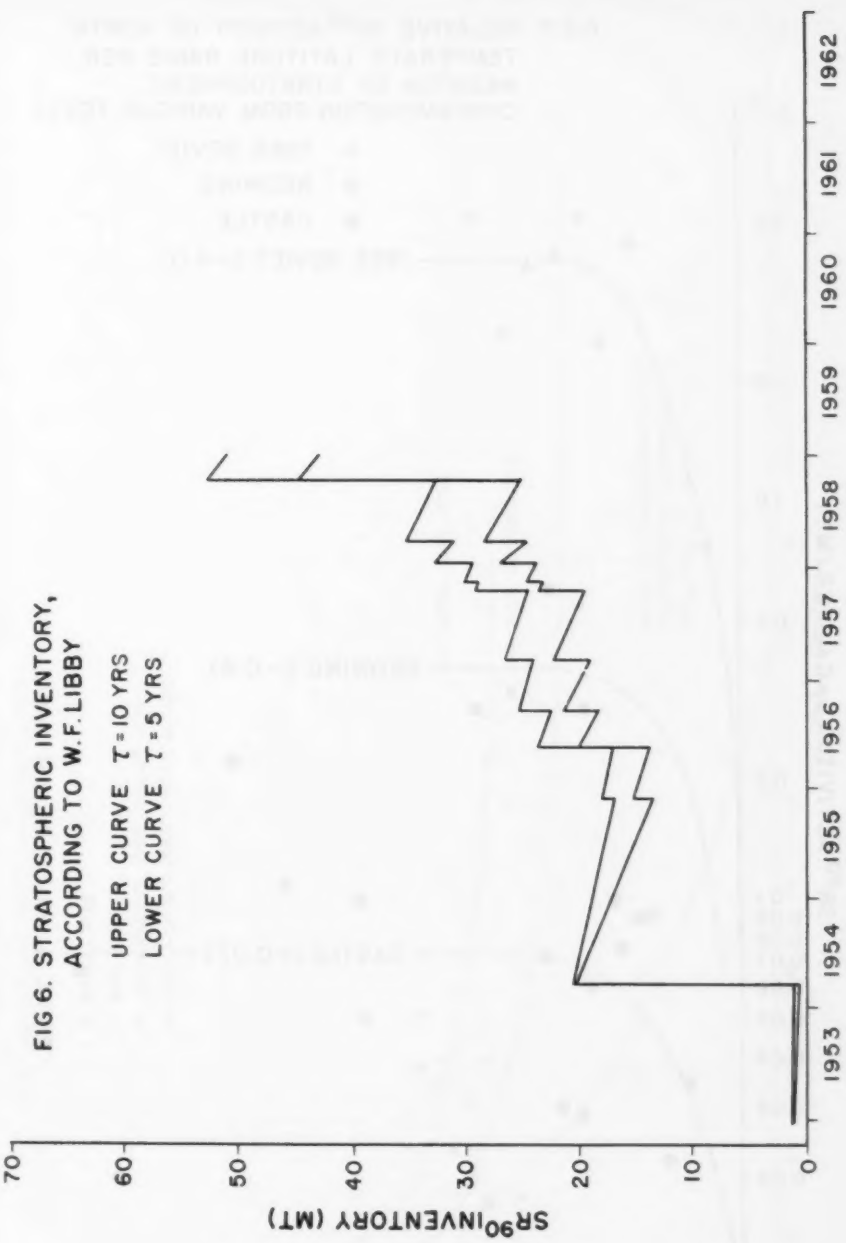
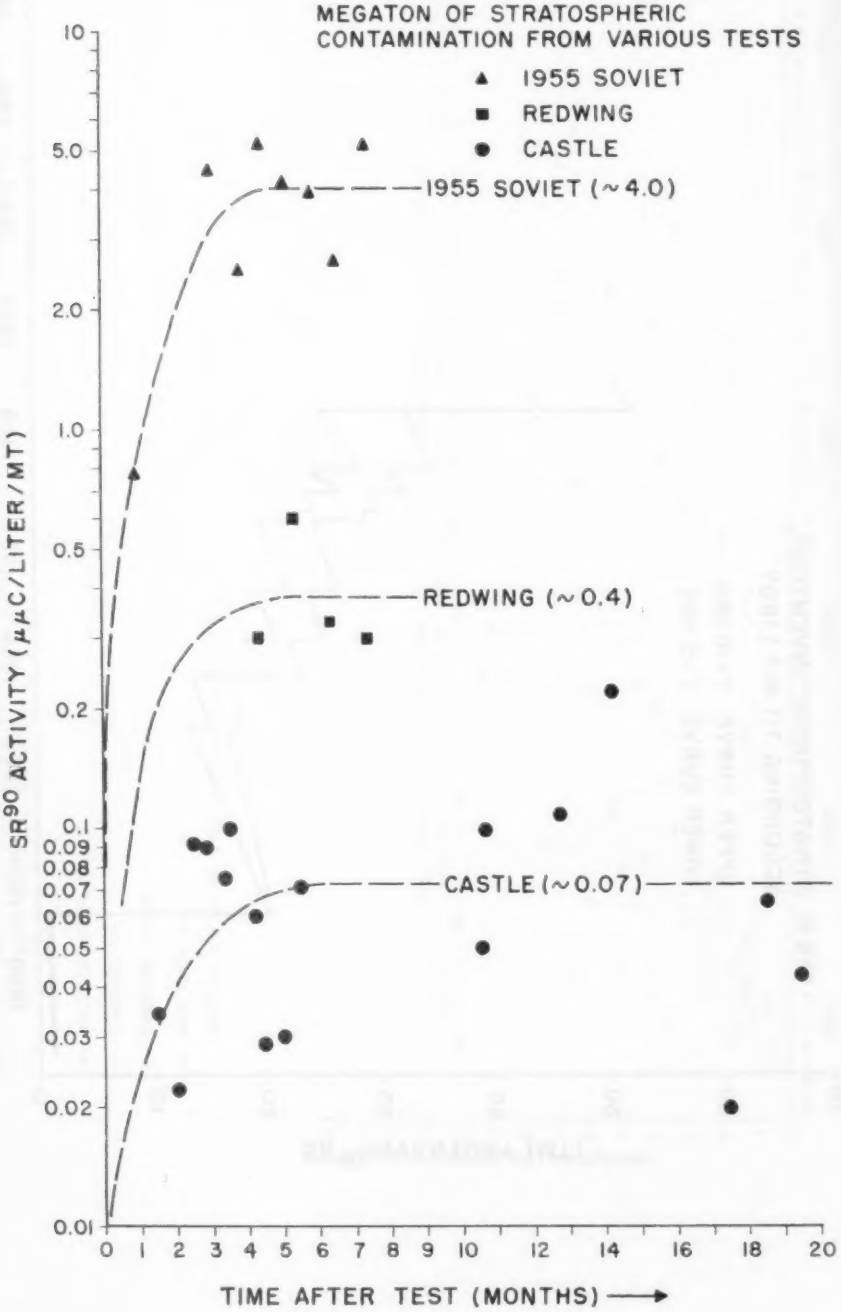


FIG 6. STRATOSPHERIC INVENTORY,
ACCORDING TO W.F. LIBBY
UPPER CURVE τ = 10 YRS
LOWER CURVE τ = 5 YRS
SR90 INVENTORY (MT)
70
60
50
40
30
20
10
0
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962

FIG. 7. RELATIVE SR^{90} ACTIVITY OF NORTH TEMPERATE LATITUDE RAINS PER MEGATON OF STRATOSPHERIC CONTAMINATION FROM VARIOUS TESTS



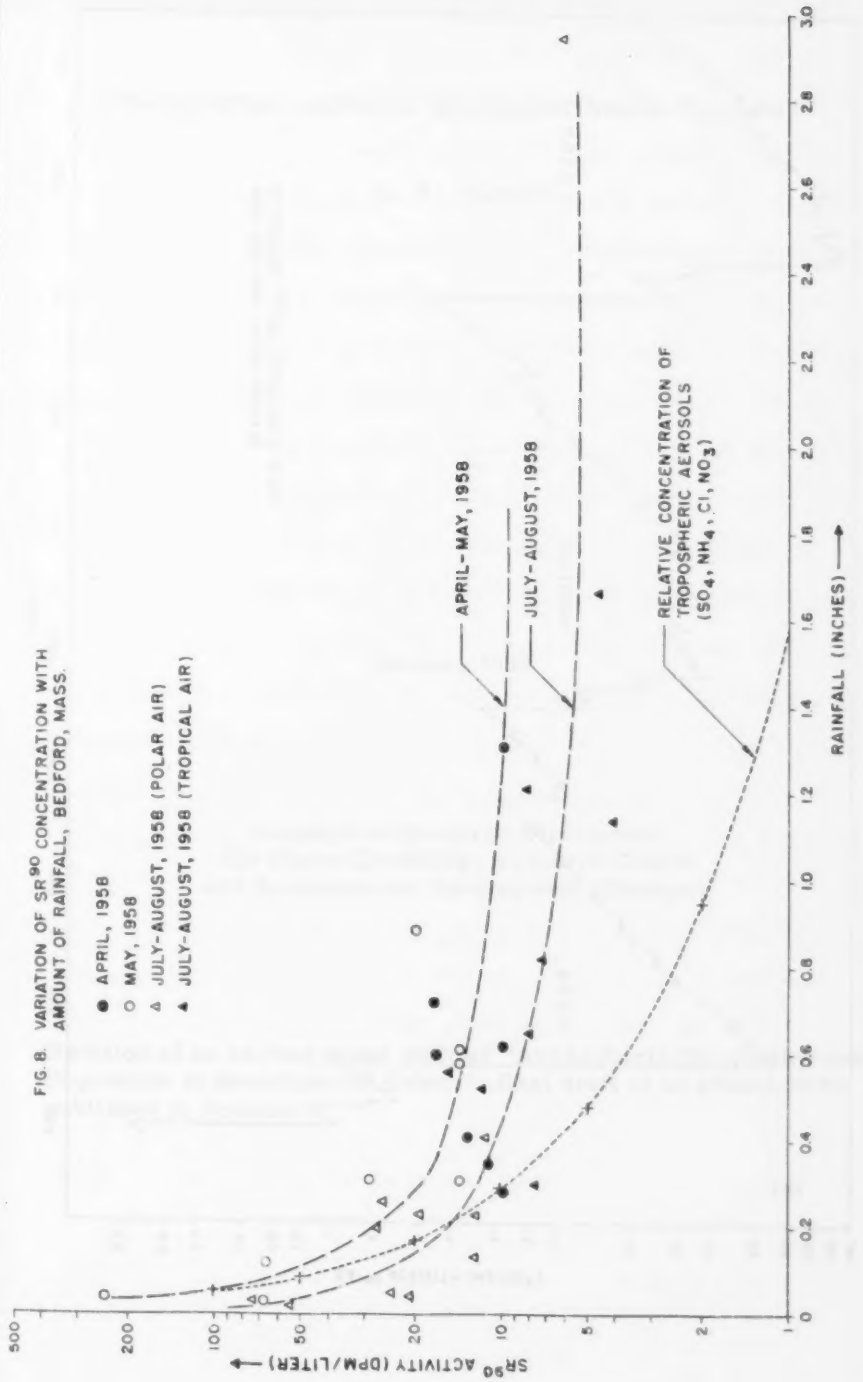


FIG. 8. VARIATION OF SR^{90} CONCENTRATION WITH AMOUNT OF RAINFALL, BEDFORD, MASS.

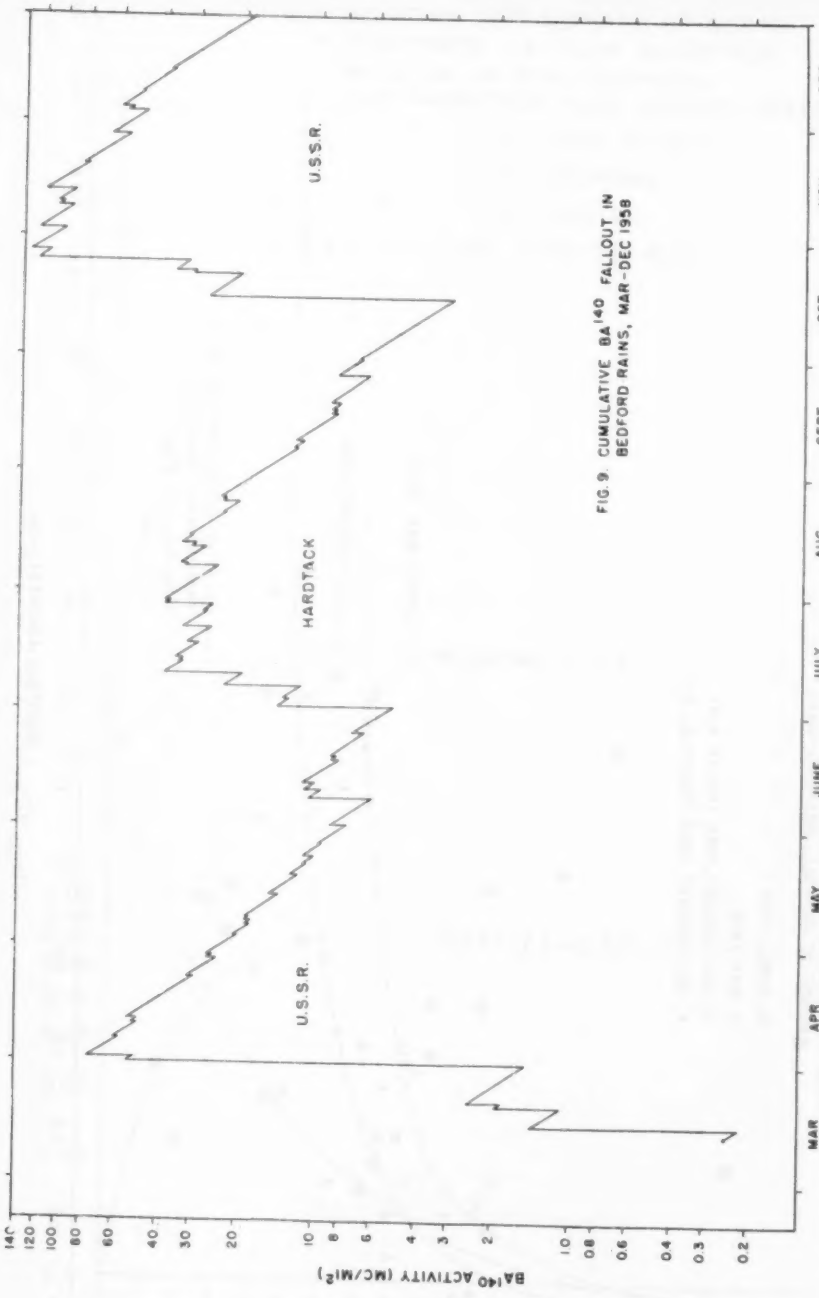


FIG. 9. CUMULATIVE Ba^{140} FALLOUT IN BEDFORD RAINS, MAR-DEC 1958

ATMOSPHERIC ASPECTS OF STRONTIUM-90 FALLOUT*

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January 1959

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Air Research and Development Command

* Revision of an earlier paper entitled "Atmospheric Circulation and Deposition of Strontium-90 Debris"; final draft of an article to be published in Science.

Review of fallout evidence indicates short stratospheric hold-up time for middle latitude atomic tests.

I. Introduction

The production of fission product strontium-90 in nuclear weapons tests, its world-wide distribution in fallout and its possible biological consequences are matters which have received increasing public attention over the past several years. The particular concern with Sr^{90} stems from its high fission yield, its long half-life of 28 years, and its chemical similarity to calcium which it follows from the soil, through vegetation and dairy products, to its final incorporation into human bone.

The physical and biological distribution of Sr^{90} activity was initially investigated on a world-wide basis in studies carried out by the University of Chicago Sunshine Project (1). Results of this work and related studies have been extensively discussed by W. F. Libby (2-5). Methods of analysis and summaries of the experimental results have been presented elsewhere (6, 7, 8). For a comprehensive treatment of the general aspects of radioactive fallout, the reader is referred to two excellent summaries (9, 10).

One of the important areas of uncertainty in our knowledge of Sr^{90} fallout is the atmospheric history of Sr^{90} debris and its consequent world-wide distribution. Experimental evidence (2, 3) has indicated that, excluding local fallout from surface bursts, debris from small nuclear weapons is circulated in the lower atmosphere, is confined to the hemisphere in which it was produced and exhibits a mean atmospheric residence time of about one month. By contrast, the debris from megaton yield weapons is substantially injected into the stratosphere, exhibits a long stratospheric residence time and may be distributed world-wide. The rate and extent of stratospheric mixing and the rate and mechanism of transport of stratospheric debris through the tropopause into the lower atmosphere are incompletely understood. Details of the mixing and scavenging of the Sr^{90} debris in the troposphere have not been fully explained, although it has been well established (3, 8, 11) that precipitation plays the dominant role in the deposition of Sr^{90} debris.

In view of our limited knowledge of large-scale atmospheric circulation and the inherent experimental difficulties in the synoptic evaluation of either the atmospheric distribution or surface distribution of Sr^{90} debris on a world-wide basis, the present stratospheric burden of Sr^{90}, its deposition rate and the consequent ground distribution can be only crudely estimated. It is the object of this paper to review some of the experimental evidence relating to the nature and atmospheric history of Sr^{90} debris and to discuss a number of experimental uncertainties and special considerations which influence the

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interpretation of world-wide fallout.

II. Sr^{90} Production

The half-life of Sr^{90} has been well established as about 28 years (12, 13). The corresponding Sr^{90} fission yield for slow neutron fission of U^{235} ranges from 5.4 to 5.8 per cent (13, 14) with an uncertainty in the absolute value of 10 to 20 per cent. Taking 1.0×10^{12} calories as the energy equivalent of one kiloton of TNT and 5.6 per cent as the U^{235} fission yield, the production of Sr^{90} is 1.14 grams per KT, corresponding to 146 curies per KT. Sr^{90} production yields will be substantially lower for fissionable materials of mass greater than 235 and will be further modified by the neutron energy spectra of nuclear weapons, with reduced yields for higher neutron energies. The Sr^{90} production for nuclear weapons is usually taken as 100 curies per KT of fission energy release. It is unlikely that the uncertainty in this value exceeds 30 per cent.

The Sr^{90} activity is produced in the mass-90 fission chain as follows:

Kr^{90} 33 sec Rb^{90} 2.7 min Sr^{90} 28 yr Y^{90} 64.6 hr Zr^{90} (stable)

Considerations of the most probable charge distribution for U^{235} thermal neutron fission (13) indicates high independent yields only for Kr^{90} and its very short-lived precursor, Br^{90}, with independent yields of Rb^{90}, Sr^{90} and Y^{90} contributing only about 15, 0.1 and 10^{-4} per cent of the total chain yield respectively. The mass-90 chain independent yield distribution for nuclear weapons will vary somewhat with mass of fissioning nuclide and

with neutron energy.

Adams, Farlow and Schell (15), in a detailed discussion of bomb debris condensation and of the physical and chemical characteristics of local fallout particles, give evidence for the occurrence of spherical radioactive particles as small as a few tenths of a micron diameter for surface coral shots and similar particles as small as 0.01 microns for surface sea water shots. They also give evidence for the isotopic enrichment of Ba^{140} and Sr^{89} on fallout particles which condense at relatively late times.

For weapons of low yield, independent yield and condensation considerations clearly indicate that Sr^{90} and other daughter products of volatile and gaseous fission products will condense later than the bulk of vaporized materials in the fireball. For high yield shots the times of debris condensation and Sr^{90} formation are more comparable and less fractionation of gaseous precursor products is to be expected. However in this case condensation takes place at stratospheric altitudes following extensive cloud dilution, leading to submicron particle formation. The long stratospheric storage time exhibited by stratospheric debris is perhaps the most convincing evidence that the particles are of submicron size. It is indicated that Sr^{90} produced in weapons tests is to a large extent concentrated in very fine particles which can remain airborne sufficiently long times to allow for extensive distribution over the world.

The delayed condensation of Sr^{90} suggests that with the possible exception

of high yield surface bursts over silicate soils, the chemical form of the Sr^{90} activity would be the oxide. During its subsequent air circulation, the strontium oxide should be readily converted to the hydroxide by the action of atmospheric water vapor. Exposure to atmospheric carbon dioxide will result in slow, partial conversion of the hydroxide to carbonate. Experimental verification of the chemical nature of Sr^{90} debris would be complicated by the attachment of the very small Sr^{90} particles to larger particles of bomb debris and to natural particulate and liquid aerosols in the atmosphere. It has been observed (8) that the Sr^{90} activity deposited in rains is substantially all in the water fraction following filtration removal of insoluble dusts. This confirms its deposition in soluble form and thus its general availability for uptake in the biosphere.

Libby (5) has provided estimates of the cumulative amount of Sr^{90} introduced into the stratosphere and troposphere for all U.S., U.K. and Russian nuclear tests up to December 1957. Total stratospheric injection is estimated (5) as 3.6 megacuries of Sr^{90} with about two-thirds from U.S. Pacific tests and one-third from Russian tests. In addition nearly 0.6 megacuries is estimated for the total distributed as tropospheric debris. These estimates were made assuming a local fallout of 80 per cent for surface land shots and 20 per cent for surface water shots. The remainder was assigned to the stratosphere for shots with total energy release of one megaton or more and to the troposphere for smaller shots.

Such estimates are subject to the several uncertainties in Sr^{90} fission yield (see above), in estimation of the total fission energy release for the various nuclear devices tested, and in the determination of the fraction of Sr^{90} production which falls out locally. Obtaining essential information for Russian nuclear tests and determination of the local fallout fraction for high yield surface shots in the Pacific test areas entail obvious difficulties. Estimates of the total Sr^{90}, which has been distributed as world-wide contamination, therefore may be in error by as much as a factor of two.

III. Fallout Models

Several alternative interpretations of Sr^{90} fallout observations have been proposed by Libby (2, 3, 5), Stewart et al (11, 16) and Machta (10, 17). Principal features of the experimental data which require explanation are the strong peak in cumulative Sr^{90} deposition in the middle latitudes of the Northern Hemisphere and the sharp increase in Sr^{90} deposition rate which has been observed in the spring for each of the past several years.

According to Libby's model (2, 3, 5) Sr^{90} debris which is injected into the stratosphere is uniformly mixed over both hemispheres in the first year or two following injection and exhibits an average storage time of 10 ± 5 years. He proposes that stratospheric debris will be distributed nearly uniformly over the world except for differences due to rainfall variations. Tropospheric debris from submegaton weapons, distributed in a narrow latitude band for each test site, is considered to account for both the high mid-latitude deposition

and the observed spring peaks in Sr^{90} fallout.

Stewart et al (11) conclude from measurements of the ratio of Sr^{89} to Sr^{90} in rains that since 1954 nearly all Sr^{90} deposited at places remote from test sites is derived from delayed fallout of stratospheric debris. They also indicate that the seasonal variation in rain concentration of Sr^{90} is in step with a similar variation in the concentration of the lower stratosphere. These authors suggest that the results are consistent with the circulation model proposed by Brewer (18) and Dobson (19).

Brewer explains the observed distribution of water vapor in the lower stratosphere by air entering the stratosphere near the equator, moving northward and sinking into the troposphere in temperate and polar regions. Dobson explains the spring rise of ozone concentration in the lower atmosphere at high latitudes as due to sinking of a cold air mass which forms above the winter pole during the late winter. Stewart and his associates attribute the high peak of Sr^{90} deposition in the middle latitudes of the Northern Hemisphere to a Brewer mode of circulation with selective downward mixing of stratospheric debris at middle latitudes. The spring peak in the Sr^{90} deposition rate is attributed to Sr^{90} rich air at higher stratospheric levels carried down in the same manner as ozone.

Machta (10, 17) has discussed some of the meteorological factors involved and raises a number of objections to both proposed models. He favors a shorter stratospheric residence time of about 5 years and, like

Stewart, attributes the high mid-latitude level of the Northern Hemisphere and the spring increase in deposition rate to stratospheric fallout, with selective latitude and season of deposition due to meteorological factors.

An alternative interpretation of the Sr^{90} fallout observations is presented below, following discussion of some of the principal features and limitations of the experimental evidence.

IV. Sr^{90} Air Concentration Data

A number of large volume surface air samples from several Northern Hemisphere locations were collected by the Naval Research Laboratory and analyzed for Sr^{90} at the University of Chicago (8). Measurements were made for collections from Washington, D. C.; Kodiak, Alaska; Port Lyautey, French Morocco and Yokosuka, Japan. The results are summarized in Figure 1. Each point of Figure 1 represents the volume weighted average of only several days collection during any one month at each location and thus may not provide a very reliable measure of average monthly air concentration. For locations other than Washington, D. C., the data may be in error by as much as 50 per cent due principally to volume uncertainty. Relative concentration values at each location are quite accurate.

These Sr^{90} data exhibit several interesting features. There is a roughly exponential rise in concentration over the four year period of observation and a general equivalence of Sr^{90} concentration range at all four locations. The 1952 Kodiak, Alaska data show contribution from the Spring 1952 Nevada tests,

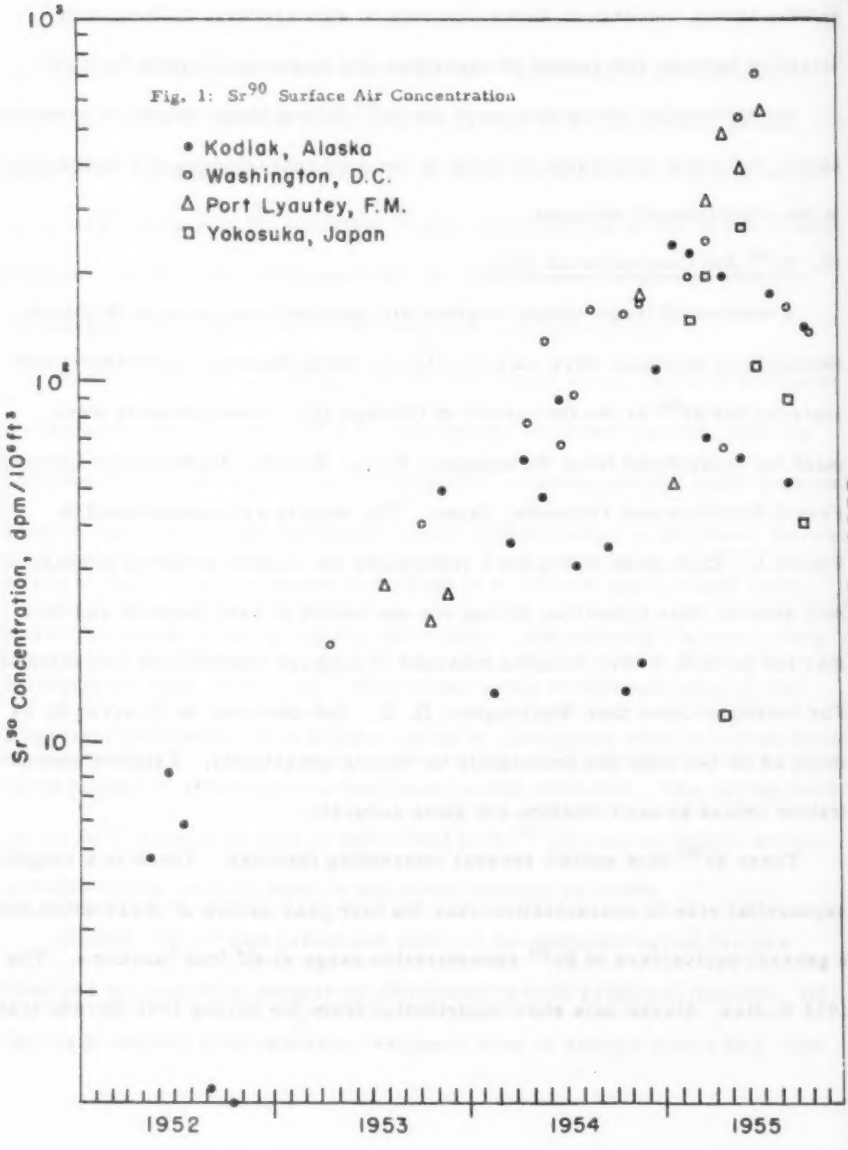


Fig. 1: Sr^{90} Surface Air Concentration
• Kodiak, Alaska
○ Washington, D.C.
△ Port Lyautey, F.M.
□ Yokosuka, Japan
Sr^{90} Concentration, dpm/10^6 ft^3
10^3
10^2
10
1952
1953
1954
1955

followed by complete removal, a behavior typical for purely tropospheric contamination. The air concentration data for the period 1953 through 1955 for all four locations demonstrate the buildup of delayed fallout from the stratosphere following the November 1952 Ivy test and the Spring 1954 Castle tests with some superimposed contribution of tropospheric debris from intermittent small weapons tests. The higher concentrations observed for Washington, D. C. and Port Lyautey during the Spring of 1955 may be due to the Spring 1955 Nevada tests or to other production or circulation considerations.

Total fission product beta activity data for surface air at Washington, D. C., furnished by I. H. Blifford, Jr. (20, 21), are presented in Figure 2 together with Sr^{90} concentration data for the same location. The plotted fission product activity data have not been corrected for decay. Mixed fission products decay exponentially with time, with approximately an order of magnitude decrease in activity corresponding to a sevenfold increase in age of the fission products. Thus the observed fission product activity levels are quite sensitive to production date and rate of arrival. With this complication the peak fission product concentrations provide a history of tropospheric contamination from small weapons tests. Peak heights for a given test area reflect tropospheric injection amounts, modified substantially by tropospheric circulation and mixing factors. The lower peak heights for Russian tests compared to Nevada tests are due to more substantial decay

and dilution due to mixing, consistent with later arrival times. The very low concentrations observed following high yield U. S. tests at the Pacific Proving Grounds reflect the limited extent of early fallout contamination from these tests.

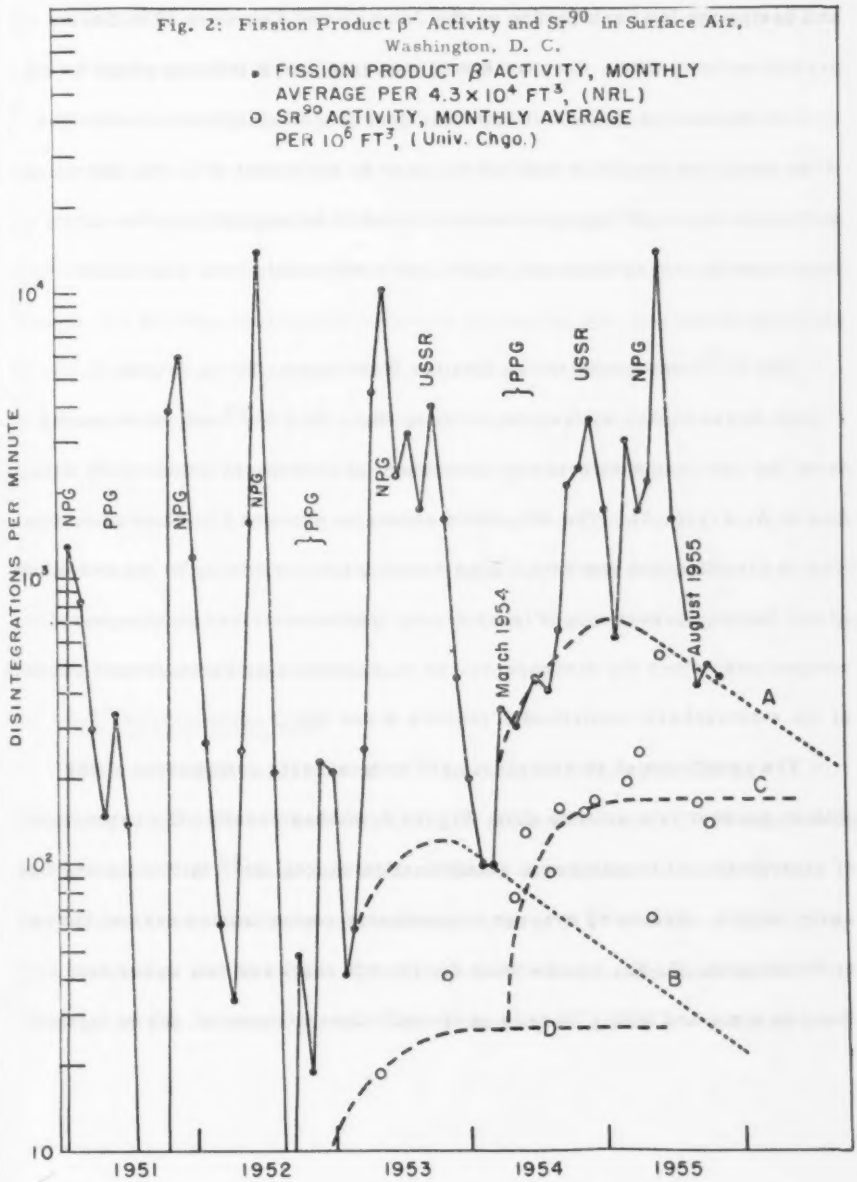
The steep slope of the fission product activity curve following small weapons tests, corrected for decay, provide a measure of the dilution and removal rate for tropospheric contamination. Using similar data for tropospheric air samples and assuming virtually complete lateral and vertical diffusion several weeks after production date, Stewart, Crooks and Fisher (16) have estimated a mean tropospheric residence time of about one month. Appreciable continued lateral diffusion would correspond to longer residence times. Particle size considerations and meteorological factors which influence diffusion and washout suggest that tropospheric residence times may be quite variable.

The fission product activity data in Figure 2 indicate essentially complete removal of tropospheric contamination between tests before November 1952. Following the November 1952 Ivy test and Spring 1954 Castle test, the minimum mixed fission product concentrations observed can be attributed to the slow downward mixing of fission products from the stratosphere. Curve A, Figure 2, is approximately fitted to the data and represents the slow mixing of Operation Castle stratospheric contamination into surface air at north temperate latitudes. Curve B is similarly

Fig. 2: Fission Product β^- Activity and Sr^{90} in Surface Air, Washington, D. C.

• FISSION PRODUCT β^- ACTIVITY, MONTHLY AVERAGE PER 4.3×10^4 FT^3, (NRL)

o Sr^{90} ACTIVITY, MONTHLY AVERAGE PER 10^6 FT^3, (Univ. Chgo.)



constructed assuming the same buildup with time following Ivy and Castle, and basing the Ivy contribution on the January and February 1954 fission product activity data. Comparison of curves A and B indicate about 5 or 6 to 1 as the ratio of the post-Castle and post-Ivy stratospheric inventories. When decay correction is applied to curve A, transport of Castle debris to surface levels at 39° north latitude is shown to be negligible in the first three months and subsequently increases continuously over a period of about one year.

The Sr^{90} air concentration data for Washington, D. C. (curve C, Figure 2) are higher by factors of two to three than Sr^{90} values computed from the resolved stratospheric component of fission product activity data (curve A, Figure 2). The difference equals or exceeds combined uncertainties in sampling and analysis. This result lends confidence to the resolution of the fission product data (Figure 2) into tropospheric and stratospheric components, since the discrepancy can be reduced only by an upward revision of the stratospheric contribution (curves A and B).

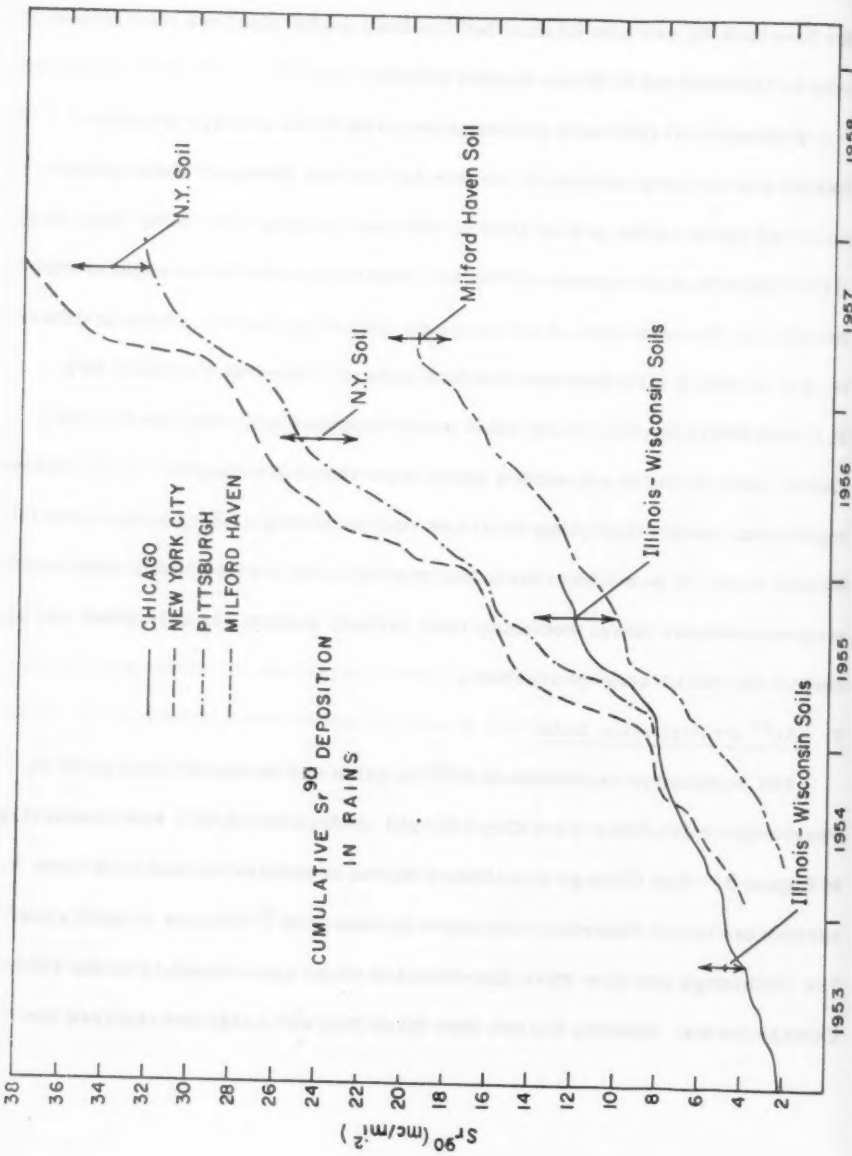
The resolution of stratospheric and tropospheric components of the fission product beta activity data, Figure 2, makes possible the estimation of contribution of tropospheric contamination to total Sr^{90} fallout during this early period. Assuming average tropospheric contamination arrival times at Washington, D. C., as one week for Nevada tests and two weeks for Russian tests and taking 30 days as the half-time of removal due to further

dilution and deposition, it is estimated that tropospheric fallout accounts for less than 50 per cent of total Sr^{90} fallout in 1953 and less than 10 per cent in 1954 and the first ten months of 1955.

Blifford et al (20) have presented records of the average monthly fission product beta activity of surface air for five Northern Hemisphere locations covering the period 1950 to 1955 and ranging from Subic Bay, P. I. ($14^{o}45'$N) to Kodiak, Alaska ($57^{o}30'$N). These records show responses for Nevada and Russian tests at all locations indicating that tropospheric debris is very widely distributed over the hemisphere. Records for Subic Bay, P. I. and Pearl Harbor, T. H. show peak responses following the Ivy and Castle tests which do not exceed those observed at Washington, D. C. following Nevada tests. Assuming about two orders of magnitude greater yield for Pacific tests, it is evident that initial tropospheric contamination from multi-megaton weapons tests, excluding local fallout, amounts to only about one per cent of the total fission production.

V. Sr^{90} Precipitation Data

The cumulative deposition of Sr^{90} in rains and snows at Chicago (6-8), Pittsburgh (8, 22), New York City (22) and Milford Haven (11) are summarized in Figure 3. The Chicago and Milford Haven deposition curves have been normalized to the observed cumulative burden of Sr^{90} of soils in each area. The Pittsburgh and New York City data are fitted approximately to the 1954 Chicago levels. Results for two New York City soils (22) are included for


CHICAGO
NEW YORK CITY
PITTSBURGH
MILFORD HAVEN
CUMULATIVE Sr90 DEPOSITION IN RAINS
Sr90 (mc/mi2)
N.Y. Soil
N.Y. Soil
Milford Haven Soil
Illinois - Wisconsin Soils
Illinois - Wisconsin Soils
1953
1954
1955
1956
1957
1958
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38

comparison. Taken together these rainfall data provide a nearly complete history of the deposition of Sr^{90} in the middle latitudes of the Northern Hemisphere. Other areas at these latitudes have experienced similar fallout history, with substantial variations in amounts of Sr^{90} accumulated due principally to differences in annual rainfall. Other factors influencing Sr^{90} deposition include seasonal distribution of rainfall, rainfall type, regional air circulation and proximity to nuclear test sites.

The rainfall data, Figure 3, indicate that only a small, perhaps negligible, fraction of present levels of Sr^{90} fallout was deposited before the advent of large scale nuclear tests. A substantial increase in annual Sr^{90} fallout has occurred in each successive year up to the end of 1957. An important feature of the rainfall data is the sharp increase in Sr^{90} deposition rate in the spring which accounts for a large proportion of the total fallout for each year. This spring increase has been attributed to tropospheric contamination from submegaton weapons tests by Libby (2, 5) and to more rapid downward mixing of stratospheric air at middle and higher latitudes in the spring by Stewart et al (11) and Machta (17). The author submits the alternative view that the spring increases are due largely to Russian tests of intermediate and high yield weapons which have injected debris into lower and intermediate levels of the stratosphere and for which the debris exhibits relatively short stratospheric residence times. The substantial spring rise in each of the past three years is attributed principally

to the immediately preceding fall and winter series of Russian tests. Substantial evidence to support this interpretation is discussed in subsequent sections of this report.

The wide range in the Sr^{90} burden observed for soils in Northern Hemisphere locations of equivalent annual rainfall and latitude for some time masked the dominance of rainfall for Sr^{90} deposition. The low Sr^{90} content of soils (3, 8) in low rainfall areas was the first evidence that rainfall is the controlling factor. Brawley, California, with less than two inches annual rainfall, held less than 0.6 mc/mi^2 in the topsoil in January 1956. This amounts to less than one tenth of levels concurrently observed in high rainfall areas of similar latitude. At Antofagasta, Chile, where it almost never rains, the January 1956 soil level was .02 mc/mi^2, about one hundredth of the concurrent level in high rainfall areas of the Southern Hemisphere. Such evidence convincingly demonstrates that the gravitational settlement of dry particles is a negligible factor in the world-wide fallout of Sr^{90}.

Results for the Mediterranean area soils, Figure 4, provide striking evidence of the dependence of the Sr^{90} soil level on rainfall. The remarkable rainfall correlation for this set of soils was first pointed out by Dr. L. T. Alexander (23). These Mediterranean lands receive the same seasonal distribution of rainfall with a marked winter maximum and extremely dry summers. In general, the rainfall over the whole area is derived from air masses of similar mixing history. Similar correlation of total Sr^{90} deposition with

Fig. 4. Sr^{90} Soil Concentration vs Annual Rainfall

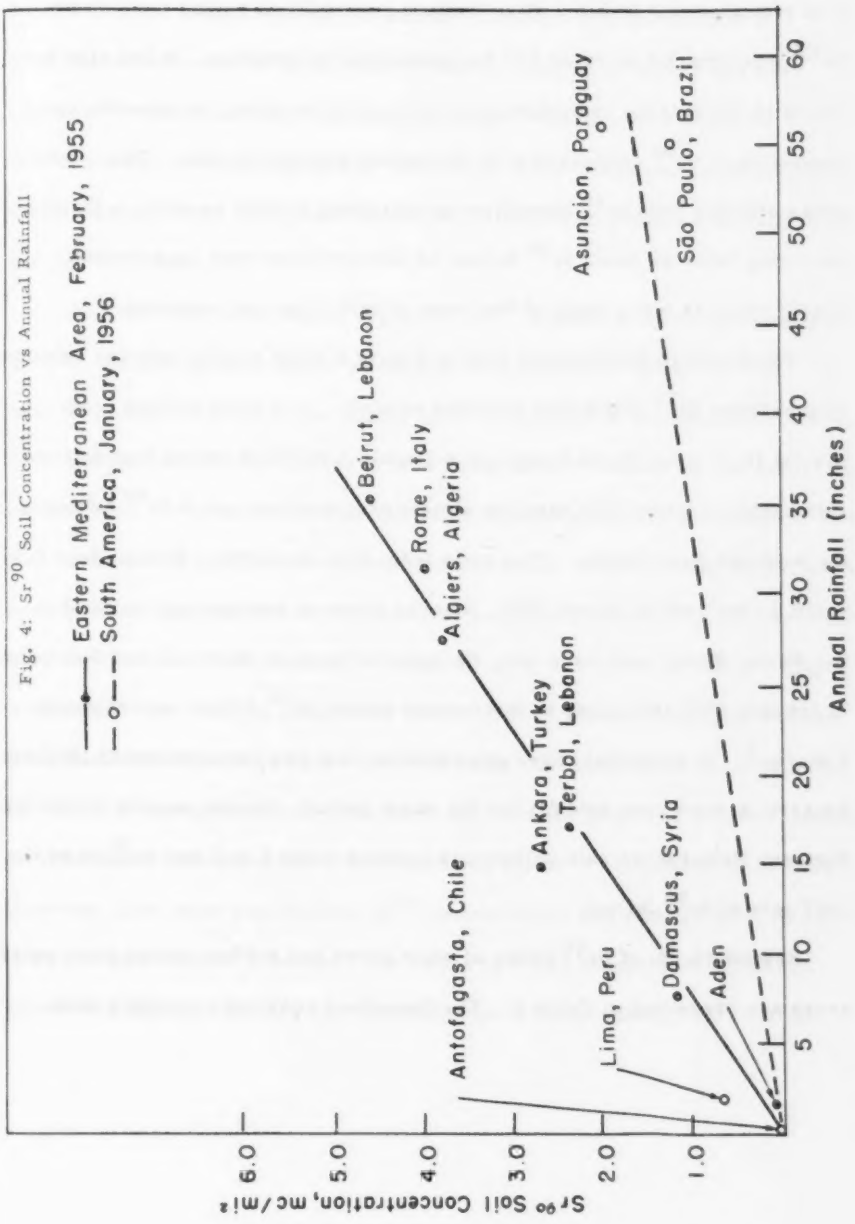


Fig. 4: Sr^{90} Soil Concentration vs Annual Rainfall

total rainfall has been observed in other limited geographical areas (24, 25). It is indicated that within a given limited geographical region the average Sr^{90} concentration in rains will be approximately constant. It has also been shown (8, 11) that for individual rains at a given location, the specific concentration of Sr^{90} decreases with increasing amounts of rain. Thus, within areas showing total Sr^{90} deposition proportional to total rainfall, a location receiving twice as much Sr^{90} fallout as another must have experienced nearly twice as many rains of the same general type and intensity.

The Southern Hemisphere data in Figure 4 show roughly similar relationship between Sr^{90} deposition and total rainfall. It is quite evident from results (2, 7, 8) for South American soils and Antarctica snows that delayed stratospheric fallout has been the almost exclusive source of Sr^{90} fallout in the Southern Hemisphere. Two soils from Belo Horizonte, Brazil, held 0.11 and 0.17 mc/mi^2 in March 1954. Nearby areas of similar high rainfall at Sao Paulo, Brazil and Asuncion, Paraguay (Figure 4) show 1.2 and 2.0 mc/mi^2 in January 1956 indicating an intervening annual Sr^{90} fallout rate of nearly 1 mc/mi^2. A somewhat lower precipitation rate has been estimated (2) from Antarctica snow core data (7) for the same period. Recent results (5, 22) for Southern Hemisphere rain collections indicate about 1 to 2 mc/mi^2/yr as the 1957 rate of Sr^{90} fallout.

Results (8, 26) of Sr^{90} assay of snow cores and surface snows from polar areas are presented in Table 1. The Greenland snow core samples were

obtained with the assistance of Dr. Henri Bader of the Snow Ice and Permafrost Research Establishment, Wilmette, Illinois. The SIPRE Site II provides reliable annual precipitation layers. Dating of layers has been checked by measurement of density and oxygen isotope-ratio profiles, both of which show seasonal variation. Additional snow cores and fresh precipitation samples from both polar areas are currently in progress of collection and Sr^{90} analysis (26).

The Greenland core shows negligible Sr^{90} deposition up to the summer of 1953, indicating essentially no mixing of tropospheric debris to this latitude and at least 9 months mixing time for arrival of stratospheric debris from the November 1952 Ivy test. Assuming about 9 months as the Antarctica arrival time for stratospheric debris from equatorial shots, the Admiral Byrd Bay core (Table 1, B) can be approximately dated. Post-Ivy and Post-Castle precipitation concentrations are indicated as about 0.85 and 3.8 dpm Sr^{90} per liter for Greenland and about 0.6 (Table 1, B, 0.5-1.5 years) and 3.4 (Table 1, A) dpm Sr^{90} per liter in Antarctica respectively. Direct comparison of the Greenland and Antarctica data cannot be made with confidence because of the difficulty of dating the Antarctica cores and because local and seasonal factors may influence both the depth distribution and the Sr^{90} concentration of snows. However, both show comparable Sr^{90} concentration and similar ratio in post-Castle to post-Ivy Sr^{90} levels. The ratios are also comparable to that observed for average surface air concentration of stratospheric Sr^{90} for the

TABLE 1: Sr^{90} DEPOSITION IN POLAR SNOWS

A. Surface Snow, Antarctica - Collected January-February 1955

Location	Depth (inches)	Sr^{90} Content (dpm/Liter)	Sr^{90} Fallout Increment[+] (mc/mi^2)
Little America III (78°S; 170°W)	0-8	3.2 ± 0.3	0.31
Little America III (1/2 mile East)	0-8	3.1 ± 0.7	0.30
Atka Bay (70°S; 08°W)	0-8	5.3 ± 0.5	0.51
Admiral Byrd Bay (69°S; 01°W)	0-12	2.0 ± 0.2	0.29
	Average	3.4 ± 0.5	

[+]Density 0.4

B. Snow Core, Admiral Byrd Bay (69°S; 01°W) - Collected Feb. 19, 1955

Estimated Age (Years)	Depth (inches)	Sr^{90} Content (dpm/Liter)	Sr^{90} Fallout Rate[+] ($mc/mi^2/yr$)
0- .25	0-12	2.0 ± 0.2	1.2
.25- .50	12-24	1.7 ± 0.2	1.0
.50- .75	24-36	0.48 ± .04	0.28
.75-1.0	36-40	0.90 ± .06	0.52
1.0 -1.25	48-60	0.48	0.3
1.25-1.5	60-72	0.29 ± 0.03	0.16

[+]Average Density 0.42

C. Snow Core, SIPRE Site II, Greenland (77°30'N; 50°30'W) - Collected September 13, 1956

Sample Period	Depth (inches)	Density	Sr^{90} Content (dpm/Liter)	Sr^{90} Fallout Rate($mc/mi^2/yr$)
Summer '55 to Summer '56	0-49	0.36	3.8 ± 0.2	2.0
Summer '54 to Summer '55	49-98	0.40	1.34 ± .16	0.79
Summer '53 to Summer '54	98-126	0.41	0.85 ± .08	0.29
Summer '52 to Summer '53	126-169	0.41	0.05 ± .12	0.03
Summer '51 to Summer '52	169-206	0.42	0.01 ± .08	0.00

same periods at Washington, D. C. (Figure 2). F. Begemann (27) has reported average cosmic ray tritium levels of 12.6 ± 1.0 tritium atoms per 10^{18} hydrogen atoms at SIPRE Site II, Greenland and 16.8 ± 1.5 T/10^{18}H for Antarctica. Assuming that average precipitation amounts in Antarctica and the Arctic are inversely proportional to cosmic ray tritium levels, a 33 per cent higher annual precipitation is assigned to the Arctic. This leads to a deposition of Ivy and Castle Pacific Test debris about 1.5 to 2 times higher in the Arctic than in Antarctica. The Arctic values may include some contribution from Russian tests. The difference might also be due to the fact that the equatorial tests were conducted at 11°N latitude, leading to unbalanced hemispherical distribution. Results for recent collections from both polar areas, including dated Antarctica cores, should allow improved comparison.

VI. Debris Age

Measurements of the ratio of Sr^{90} to total fission product activity, Sr^{89} and other isotopes have been carried out (11, 25) in order to distinguish the relative contribution of tropospheric and stratospheric debris to total Sr^{90} deposition and thus to try to account for the sharp increase in Sr^{90} deposition rate in the spring (Figure 3). Results of Sr^{89} and Sr^{90} measurements in Milford Haven rains reported by Stewart et al (11) are reproduced in Figure 5. Assuming a mean age of 35 days for tropospheric debris from small weapons tests and further assuming that all Sr^{89} is derived from such

tests, Stewart (11) estimates upper limits of 5 and 12 per cent of the total Sr^{90} fallout in the spring of 1955 and 1956 respectively as tropospheric debris. He then concludes that Sr^{90} fallout since 1954 has been substantially all derived from old stratospheric debris and accounts for the spring peaks as due to more rapid downward mixing of stratospheric air during the spring.

The assumptions made in the above analysis warrant further consideration. The mean residence time for tropospheric debris may vary appreciably with latitude, season and weather pattern. However, the range of possibilities is unlikely to alter the conclusion that tropospheric debris from small weapons tests accounts for only a small fraction of the total Sr^{90} fallout. The assumption that the increase in Sr^{89} activity (Figure 5) is due to tropospheric contamination from small weapons tests appears reasonable at first sight, considering the widely accepted view that stratospheric debris exhibits a mean residence of 5 to 10 years. However, each increase in rate of Sr^{90} deposition (Figure 5) appears to be accompanied by a relatively greater increase in Sr^{89} deposition, indicating contribution from recent tests. If these substantial increases in both Sr^{89} and Sr^{90} are related, an explanation other than small weapons tests or seasonal mixing effects is needed. A reasonable possibility is that the Sr^{89} is largely of stratospheric origin and each peak in deposition involves debris injected into the stratosphere only a few months earlier. It should be noted that Russian atomic tests of high yield devices have been conducted in the fall or winter of each of the past

three years, preceding the three periods of most intense Sr^{90} fallout at north temperate latitudes.

Results of Sr^{89} and Sr^{90} measurements in U. S. rains carried out by the Health and Safety Laboratory and reported by Collins and Hallden (25) are presented in Table 2. The calculated production dates (Column 4, Table 2), computed from the average monthly concentration data for March, April, May and June, augur well for the fall 1955 Russian tests as a prominent source. It would be quite fortuitous if the apparent age of a mixture of fresh tropospheric and old stratospheric contamination remained so nearly constant for four months. Sr^{89}/Sr^{90} ratios for Milford Haven rains (Figure 5) show the same trend during this period, with values about one-half those observed for U. S. rains (Table 2). The difference in ratios may be due to errors in

Table 2: Debris Age from Sr^{89}/Sr^{90} Ratio in U. S. rains - March-July 1956

Sampling Month	Average Sr^{90} Deposition ($mc/mi^2/mo$)	Sr^{89}/Sr^{90} Average	Calculated Production Date
March 1956	1.2	22	September 1955
April 1956	1.1	9.7	August 1955
May 1956	1.6	9.3	September 1955
June 1956	1.0	7.0	October 1955
July 1956	1.5	29	February 1956

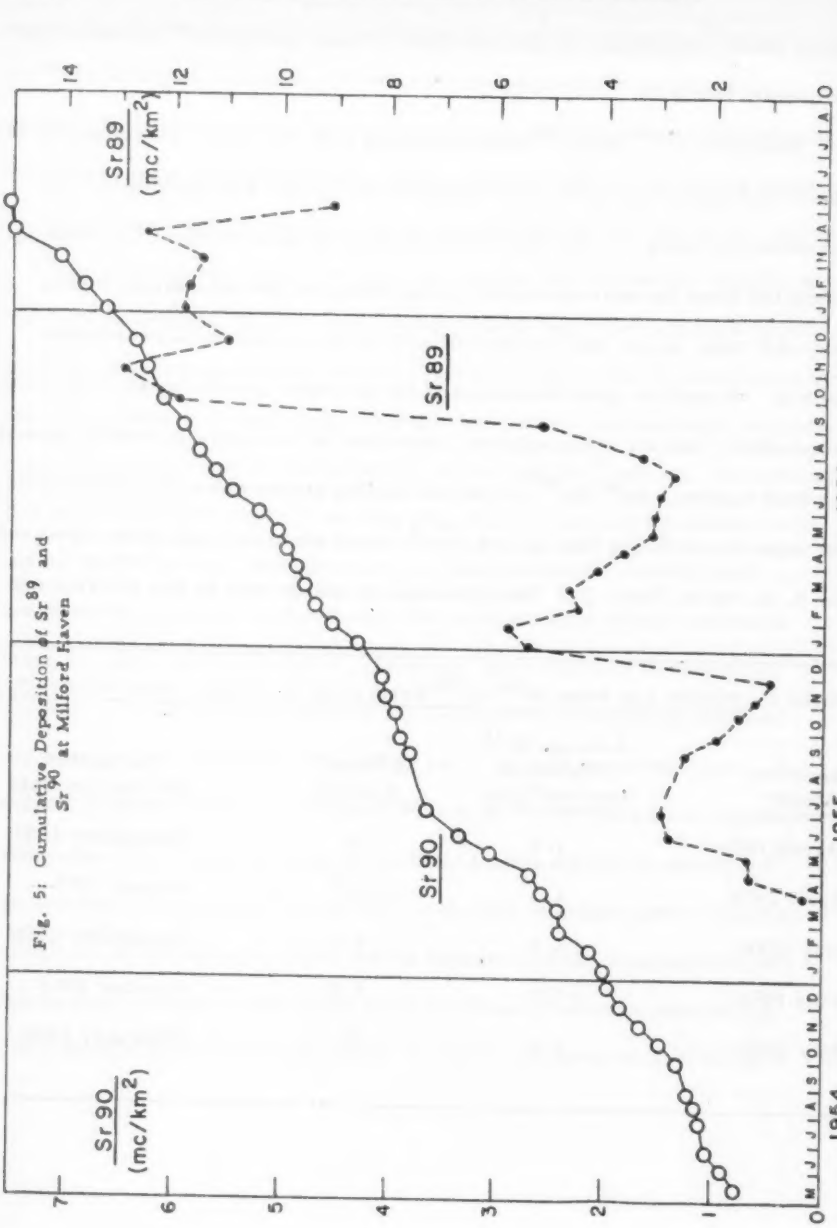


Fig. 5: Cumulative Deposition of Sr^{89} and Sr^{90} at Milford Haven

analysis or to real differences in the relative contribution of older stratospheric debris to the Sr^{90} fallout in these two regions. Considering the methods of analysis (25, 28) and the magnitude of the Sr^{89}/Sr^{90} ratios, Figure 5 and Table 2, it is considered that analytical errors should not introduce more than 50 per cent error in ratios, amounting to about one month variation in apparent age.

The above suggestion that the winter-spring 1956 Sr^{89} concentration in rains is largely stratospheric in origin implies that tropospheric contribution of Sr^{90} from small weapons tests is even lower than Stewart's estimates. Blifford et al (20) show appreciable mixing of debris from Nevada and Russian tests over the whole range of latitudes from 15°N to 57°N. A cloud height of about 77,000 feet for a one megaton explosion has been reported (29). Tropopause heights range from about 55,000 feet at the equator to 30,000 feet at high latitudes. It is indicated that tropospheric contamination results only from surface or low altitude nuclear detonations below about 100 to 200 kilotons in yield, necessitating downward revision of tropospheric contamination estimates. The reduced inventory and widespread distribution of tropospheric debris are consistent with the small percentage contribution of tropospheric contamination to total Sr^{90} fallout which has been variously estimated.

Recent experimental results (26) support the view that stratospheric contamination from high yield Russian tests appears in high concentration

at lower stratospheric levels and exhibits relatively short stratospheric residence time. Air filter samples collected from lower stratospheric levels in the Northern Hemisphere during April 1958 showed very high concentrations of short-lived fission products at middle-latitudes and only old fission products at low latitudes. The Ba^{140}/Sr^{90} ratios for a series of 15 individual Bedford rains (26) in the period from 2 to 8 weeks following the last announced Russian test in March 1958 decreased regularly with the 12.8 day half-life of Ba^{140}. Since the Sr^{90} deposition rate was slowly increasing during this period, the only reasonable physical interpretation appears to be that even the short-lived Ba^{140} activity is of stratospheric origin. Rapid downward mixing of stratospheric debris from Russian atomic tests is indicated.

VII. Surface Distribution

The approximate world-wide distribution of Sr^{90} over land areas in mid-1956, based on Health and Safety Laboratory soil measurements (22), is presented in Figure 6. This representation somewhat overemphasizes U. S. levels in order to show recent annual changes in the north temperate latitude levels where adequate soil data was available. These soils were sampled to a depth of six-inches and the Sr^{90} was quantitatively extracted with hydrochloric acid before assay. A few soils from areas of abnormally low or high precipitation were omitted in order to provide a reasonably representative distribution. The Arctic and Antarctic levels of 1.8 and

1.2 mc/mi^2 respectively for mid-1956 are based on the data in Table 1 and assume mean annual precipitation of 10 inches of water equivalent in the Arctic and 8 inches in Antarctica.

The Southern Hemisphere distribution includes representative soil data from South America, South Africa, Australia and New Zealand. Variations in soil levels appear to roughly correlate with total annual rainfall, the principal cause of variation in observed Sr^{90} burden (Figure 4). Other variations are at least partly due to errors in sampling and analysis and to differences in sampling times. Except for the reduced deposition in Antarctica, there is no striking variation in latitudinal distribution that can be related to features of the general atmospheric circulation. Since atomic tests in the Southern Hemisphere have been very limited in number and yield, the Southern Hemisphere fallout is essentially all derived from stratospheric debris. The 1956 Southern Hemisphere levels may be accounted for by U. S. equatorial tests alone.

In the Northern Hemisphere the striking feature is the heavy fallout in the middle latitudes. Comparable high levels are observed in Northern United States, Southern Canada and Northern Europe. Within a limited geographical area, cumulative soil level will be approximately proportional to total rainfall. Additional large variations for areas of similar latitude and annual rainfall will occur due to seasonal distribution of rainfall in relation to the spring peak in deposition rate. There is also a striking

variation in deposition with latitude in relation to the zone of entry for stratospheric debris from Russian tests. Proximity to small weapons tests sites, variations in average rainfall type and circulation features will exert some additional influence on the distribution.

VIII. Discussion and Conclusions

It was inferred from debris age considerations and other evidence above, that the spring peak in Sr^{90} fallout (Figure 3) may involve substantial contribution from stratospheric debris of short residence time injected during the immediately preceding Russian test series. This possibility is strongly reinforced by consideration of alternative interpretations. Estimates based on Sr^{89}/Sr^{90} ratios and other evidence discussed above indicate that the Sr^{90} contribution from tropospheric debris following small weapons tests is minor. Selective downward mixing of old and thus well-mixed stratospheric debris during the late winter and spring, in accordance with Dobson's interpretation of the ozone data also can be questioned as an explanation for the spring peaks in Sr^{90} deposition rate. If seasonal variation in downward mixing of stratospheric Sr^{90} debris were an important factor independent of production considerations, the effect should be evident in southern hemisphere precipitation data. Stewart's results (11) for Ohakea (40°12'S; 175°23'E) show minor seasonal variation in Sr^{90} content of rains compared with variations observed at middle latitudes of the northern hemisphere. Unless there are large differences in degree of

effect for the two hemispheres, the striking spring peaks in Sr^{90} fallout at north temperate latitudes must be attributed largely to stratospheric debris from the preceding Russian tests. It should also be mentioned that the spring peak in ozone concentration (30) is very broad and low in amplitude whereas the Sr^{90} fallout peaks at north temperate latitudes are not only of greater amplitude, but are not confined to the spring season (Figures 3 and 5).

Since tropospheric injections of Sr^{90} contamination can be reasonably assumed to contribute only a small fraction of total Sr^{90} fallout, the surface distribution, Figure 6, must be explained in terms of the production schedule, the injection latitudes and the mixing history of intermediate and large scale detonations. The 1956 Southern Hemisphere distribution is without question due largely to the November 1952 Ivy and spring 1954 Castle tests with stratospheric injection at 11° north latitude. The Southern Hemisphere distribution exhibits no appreciable variation with latitude. This implies that stratospheric debris from equatorial tests is not selectively mixed downward at middle latitudes to an appreciable degree. Assuming similar Northern Hemisphere distribution for equatorial test debris, the north temperate latitude peak in distribution must to a very large extent be the consequence of Russian tests.

Comparison of the post-Ivy and post-Castle deposition levels in polar snows makes possible an approximate material balance interpretation of

the 1956 surface distribution (Figure 6) in terms of latitude of injection for high yield tests. The Arctic deposition rate for equatorial tests is estimated as 1.5 times that of Antarctica. Taking 1.5 times the Southern Hemisphere levels as the Northern Hemisphere distribution for equatorial tests and assigning 5 per cent of Northern Hemisphere levels as tropospheric fallout, the balance is attributed to Russian tests. This analysis credits Russian tests with roughly three-fourths of the Sr^{90} fallout in the north temperate latitude belt.

Consideration of the possible circulation and mixing histories for clouds of stratospheric debris injected at equatorial and middle latitudes leads to no serious inconsistencies with the above analysis. The Brewer (18) and Dobson (19) views of atmospheric circulation indicate poleward flow in the stratosphere and downward mixing at middle and higher latitudes, with more rapid downward mixing in the spring. The influence of the jet stream may further enhance the downward mixing of stratospheric air at middle latitudes. Assuming these views of circulation to be correct, it is indicated that the timing and latitude of Russian tests fortuitously lead to short storage times and to a quite selective zone of downward mixing and deposition. A quite different mixing history is to be expected for stratospheric debris injected at equatorial latitudes. The debris should diffuse rapidly throughout a broad zone of the equatorial stratosphere under the influence of the strong easterlies in this region. Debris in the equatorial stratosphere will

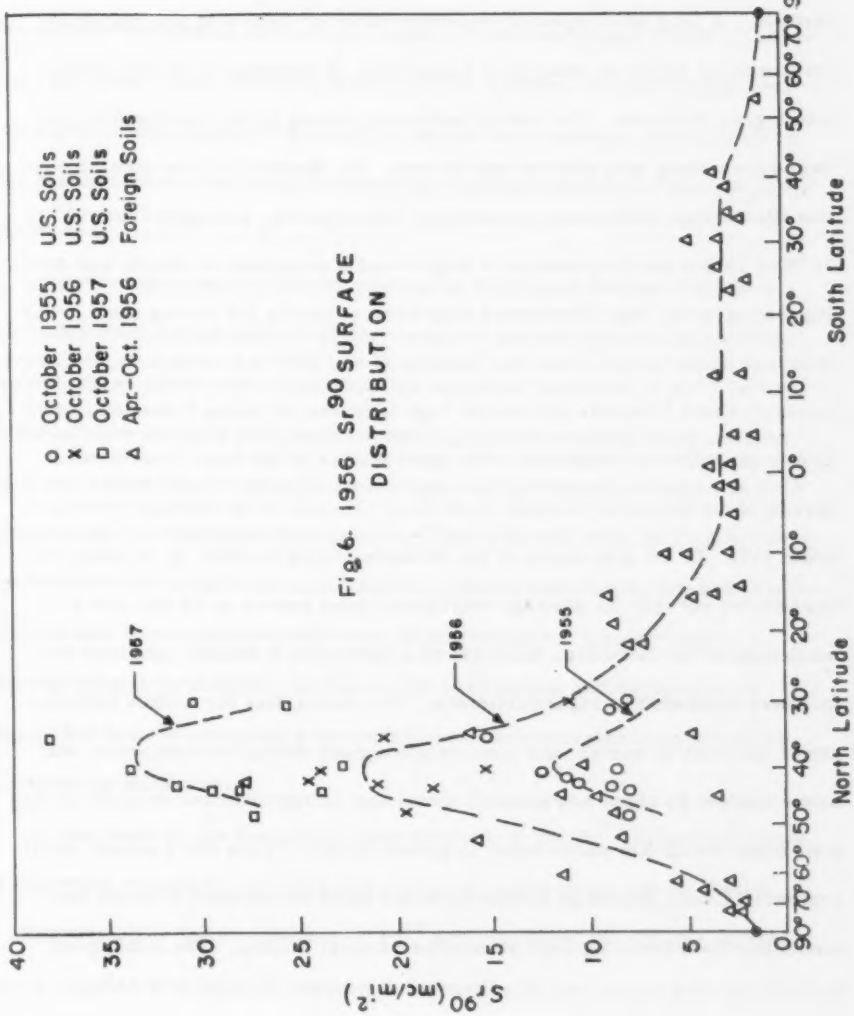


Fig. 6. 1956 Sr^{90} SURFACE DISTRIBUTION

subsequently mix into higher latitudes of both hemispheres, with perhaps somewhat more into the Northern Hemisphere for U. S. tests at 11°N latitude. A long stratospheric residence time for debris in the equatorial stratosphere would be equated to a slow rate of exchange from this region into higher latitudes. The rate of poleward mixing in the stratosphere may vary appreciably with altitude and season. H. Wexler (31) has pointed out that the average meridional geostrophic wind speeds, averaged from 10° to 70°N at 19 Km are a minimum in August and a maximum in March and April, suggesting more rapid northward migration of debris for spring tests. The observed initial arrival time for equatorial test debris at mid-latitude ground levels in about 3 months (21) and at high latitudes following 9 months (Table 1, C) are qualitatively consistent with observations of the rate of northward spread of the Krakatoa volcanic dust cloud (31) and of the vertical mixing of ozone (30). In his discussion of the Krakatoa cloud spread, H. Wexler (31) has pointed out that the average meridional wind speeds at 19 Km are a maximum at low latitudes, decrease to a minimum at middle latitudes and increase somewhat at higher latitudes. The ozone data for middle latitudes shows the peak in surface air concentration post-dating the maximum total ozone content by about two months, providing an approximate vertical mixing time from the 20 Km ozone layer to ground levels. Thus the 3 month initial arrival of Castle debris at middle latitudes must correspond to about one month northward mixing and two months vertical mixing. The subsequent

slow increase in middle-latitude Sr^{90} concentration and late arrival of Sr^{90} fallout in polar areas reflect slow exchange out of the equatorial stratosphere northward through the region of low meridional winds. Clouds of nuclear debris from Russian tests at 52°N latitude, injected in the region and usually in the season of lowest meridional wind speeds, should undergo little diffusion before mixing downward perhaps quantitatively into the lower atmosphere.

It appears that equatorial detonations of high yield devices lead to a reasonably well mixed equatorial stratosphere and subsequent circulation does not effect appreciable latitudinal or seasonal variation in Sr^{90} fallout. Middle latitude tests of intermediate and high yield weapons must account to a large extent for the observed seasonal and latitudinal variation in Sr^{90} deposition in the Northern Hemisphere. The differences in mixing history and ultimate distribution for stratospheric debris injected at low and middle latitudes are important consequences of stratospheric meteorology. Seasonal effects undoubtedly influence the circulation and deposition of fallout, but may be assigned a secondary role in the explanation of major variations in fallout rate.

On the basis of the foregoing consideration of the Sr^{90} fallout evidence, the following summary remarks and tentative conclusions can be stated.

Uncertainties in the amounts of Sr^{90} activity injected into the stratosphere coupled with lack of adequate information on the origin and distribution

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of the Sr^{90} already deposited over the earth's surface inhibit reliable assessment of stratospheric hold-up times and limit the accuracy of fallout distribution predictions.

Precipitation washout is the predominant mechanism of Sr^{90} fallout. Gravitational fall of dry particulate material appears to contribute a negligible fraction of the total Sr^{90} fallout.

Within a limited geographical zone of similar circulation and characteristic rainfall type, the cumulative Sr^{90} fallout will be approximately proportional to total rainfall. In the Northern Hemisphere there is a marked variation in Sr^{90} fallout in relation to the zone of entry for stratospheric debris from Russian tests. Seasonal distribution of rains in relation to the spring increase in air concentration will further modify the Sr^{90} distribution. In the Southern Hemisphere the annual rainfall appears to be the major consideration affecting Sr^{90} distribution.

Stratospheric debris injected by high yield atomic tests at equatorial latitudes appears to undergo rapid diffusion throughout a broad region of the equatorial stratosphere and subsequently mixes poleward with roughly equivalent amounts contributed to each hemisphere. A relatively long stratospheric storage time of perhaps 5 to 10 years and approximately uniform hemispherical distribution, reduced toward the pole, is indicated in this case.

Clouds of stratospheric debris from middle latitude nuclear detonations

apparently reach lower stratospheric levels after only limited diffusion and release substantially all of their contamination into a restricted latitude zone during the first six months or so. The spring peaks in Sr^{90} deposition rate and the band of heavy fallout at north temperate latitudes can be attributed principally to high yield Russian nuclear tests.

The direct injection of contamination into the troposphere is apparently limited to detonations not exceeding 100 to 200 kilotons. Sr^{90} activity from this source is quite widely dispersed and has amounted to only a few per cent of total fallout to date.

The total Sr^{90} fallout at north temperate latitudes from high yield tests at these latitudes will be higher by a substantial factor than that from equivalent equatorial tests. Perhaps even more important, the short stratospheric hold-up time for middle latitude tests allows for substantial deposition before decay of the shorter-lived fission products which contribute to external gamma radiation and its possible genetic effects. It is clear that the predicted contamination consequences of high yield detonations at north temperate latitudes must be revised upward from estimates based on 5 to 10 year periods of stratospheric storage.

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1. Supported by the Division of Biology and Medicine, U. S. Atomic Energy Commission, under Contract AT (11-1)-281. Initiated and directed by W. F. Libby, July 1953 to October 1954. Continued under direction of E. A. Martell, October 1954 to termination in August 1956.

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32. The author is indebted to Dr. W. F. Libby, Dr. L. T. Alexander, Dr. R. A. Craig, Dr. C. E. Junge and I. H. Blifford, Jr., for numerous helpful discussions and suggestions. Appreciation is extended to Dr. Henri Bader of the Snow, Ice and Permafrost Research Establishment, Mr. Paul Humphrey of the U.S. Weather Bureau and members of the U.S. International Geophysical Year organization for their generous assistance in obtaining the Antarctica and Greenland snow samples.

Representative HOLIFIELD. Our next witness will be Dr. Libby of the Atomic Energy Commission.

Dr. Libby, we are glad to have you come forward.

STATEMENT OF DR. WILLARD F. LIBBY,[1] COMMISSIONER, ATOMIC ENERGY COMMISSION

Dr. LIBBY. Thank you, sir.

Representative HOLIFIELD. Dr. Libby, we recognize the fact that a great deal of this material used by these scientists was brought to the front by your efforts and, as always, the committee wants to express its appreciation of the work that you have done in bringing a great deal of information out into the public forum and furnishing it to your fellow scientists for their independent evaluation.

Dr. LIBBY. Mr. Holifield, those are very kind remarks.

The intensive series of bomb tests fired by the U.S.S.R. during last October affords a unique opportunity to test whether stratospheric radioactive fallout from injections made at polar latitudes differs appreciably in distribution or fallout rates from that date due to equatorial explosions, such as the United States and United Kingdom have fired.

The Russian October series is estimated on the basis of assumptions previously described, to have added about 12.5 to 15 megatons equivalent of fission products to the stratosphere, whereas the previous inventory on the same basis was about 25 to 30 megatons equivalent so the Russian addition amounted to a sudden increase of about 50 per-

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[1] Libby, Willard Frank: Born in Grand Valley, Colo., Dec. 17, 1908, son of Ora Edward and Eva May (Rivers) Libby. Attended grammar and high school near Sebastopol, Calif., 1913–26; University of California, Berkeley, 1927–33; B.S. 1931, Ph. D. 1933; also recipient of Sc. D., Wesleyan University, 1955; Syracuse University, 1957; Trinity College of University of Dublin, 1957 (honoris causa).

Appointed instructor, Department of Chemistry, University of California, in 1933, and during the next 10 years was promoted successively to assistant professor and associate professor of chemistry; in 1941 was awarded a Guggenheim Memorial Foundation fellowship, electing to work at Princeton University. On December 8, 1941, this fellowship was interrupted for war work in the Manhattan District project at Columbia University, on leave from the Department of Chemistry, University of California, until 1945. At the end of the war, in 1945, accepted the position of professor of chemistry, Department of Chemistry, Institute for Nuclear Studies (now Enrico Fermi Institute for Nuclear Studies) of the University of Chicago, remaining until appointment by President Eisenhower on Oct. 1, 1954, as a member of the U.S. Atomic Energy Commission; reappointed by the President to a 5-year term on June 19, 1956.

Has done a wide range of scientific advisory and technical consultant work with industrial firms participating in the Institute for Nuclear Studies, as well as with defense agencies, scientific organizations, and universities. From 1945 to 1952 was a member of the Atomic Energy Commission's Committee of Senior Reviewers; 1950 to 1954 served as a member of the General Advisory Committee to the Commission; Guggenheim Memorial Foundation fellow, 1941, 1951, and 1959–62; continues to serve as an adviser on fellowships to the Guggenheim Foundation; is a research associate of the Carnegie Institution of Washington.

Became well known at the University of Chicago for work on natural carbon 14 (radiocarbon) and natural tritium, and received the Research Corp. Award for 1951 for the radiocarbon dating technique; in 1954, was awarded the Chandler Medal by Columbia University for outstanding achievement in the field of chemistry; Remsen Memorial Lecture Award, 1955; City College of New York Bicentennial Lecture Award, 1956; recipient of 1956 American Chemical Society Award for nuclear applications in chemistry; Elliott Cresson Medal, Franklin Institute, 1957; Willard Gibbs Medal Award by American Chemical Society, 1958; Priestly Memorial Award, Dickinson College, 1959; Albert Einstein Medal Award, 1959.

Author of book, "Radiocarbon Dating," University of Chicago Press, 1952; second edition, 1955; author of numerous articles in scientific journals.

Member American Chemical Society, American Physical Society, American Association for the Advancement of Science, National Academy of Sciences, American Philosophical Society, American Academy of Arts and Sciences, Washington Academy of Science, Heidelberg Academy of Sciences, Bolivian Society of Anthropology, Pi Mu Epsilon, Sigma XI, Phi Beta Kappa, and Alpha Chi Sigma. Member, Cosmos Club of Washington, D.C.

Married to the former Leonor Hickey of King City, Calif. Twin daughters, Janet and Susan, born in 1945.

cent and, as we shall see later, this on the basis of late information probably is low, the most likely figure being 80 percent.

(Articles published by Dr. Libby:)

RADIOACTIVE FALLOUT ARTICLES PUBLISHED BY DR. W. F. LIBBY SINCE CONGRESSIONAL HEARINGS ON RADIOACTIVE FALLOUT BEFORE THE JOINT COMMITTEE ON ATOMIC ENERGY IN SPRING, 1957

W. F. Libby, U.S. Atomic Energy Commission

Continental Water Balance, Ground Water Inventory and Storage Times, Surface Ocean Mixing Rates and World-Wide Water Circulation Patterns From Cosmic-Ray and Bomb Tritium. F. Begemann and W. F. Libby. Geochimica et Cosmochimica Acta. 12, 277–296 (1957).

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Dr. LIBBY. Since the last hearing before the Joint Committee on Atomic Energy on radioactive fallout, in June 1957, there has been a continuing discussion of the points raised at that time about the mechanism of stratospheric fallout and the length of the storage time, and one new theory has been introduced. The new theory is that of Dr. E. A. Martell,[2] who has suggested recently that nuclear explosions conducted in the polar latitudes and which inject radioactive fallout into the stratosphere may have a stratospheric residence time of about 1 year, a time much shorter than for those tests conducted in equatorial latitudes which have a residence time of the order of several years.

Also, the Department of Defense has tentatively concluded, on the basis of data which it has collected, together with the Atomic Energy Commission's stratospheric balloon data, that the residence time is about 3 years instead of 6.

There is a factor of 0.7 between residence times and half time which is consistent with what Dr. Machta said.

At the time of the last hearings, Dr. Machta emphasized that the well established nonuniformity of the total fallout in the Northern

[2] Martell, E. A., "Atmospheric Aspects of Strontium 90 Fallout." (See p. 841.) Cambridge Research Center. Science (129 1197–1206 (1959).) Dr. Martell's theory is similar to a suggestion made by Dr. Machta during the last hearings in 1957 which in turn was based on a paper by Brewer.

Hemisphere with a peak in the middle latitudes might be due to a natural characteristic of the circulation of the stratosphere which concentrates stratospheric fallout in these latitudes. The author has pointed out the fact that the major test sites in the United States and the U.S.S.R. lie in these latitudes and that tropospheric fallout from these sites which, because it is airborne only 1 month or so on the average and, consequently has relatively little chance to spread in the north-south direction, could contribute a band of early fallout around the earth in the general latitude of the test site which might account for a large part of the peak and, in fact, has shown—table III, address of March 13, 1959 (see vol. 3, app. C)—by comparison of foreign with domestic soil data that the United States had, in October 1956, about twice as much total strontium 90, some 17.7 mcs/mi², strongly indicating that at least half of the peak in the United States in 1956 was tropospheric and due to tests in Nevada.

Since that time further data have been accumulated on the total deposit up to early 1958 by analyses of soil samples collected abroad in the spring and early summer of 1958 and in the United States in October 1958 by Dr. Lyle T. Alexander of the U.S. Department of Agriculture.

These data again show a considerable excess of strontium 90 deposited in the Northern Hemisphere and a local U.S. excess of about 15 mcs/mi² over the other parts of the Northern Hemisphere in the same latitudes which averaged about 26 mcs/mi².

The data continue to raise the old question as to whether this excess of the Northern Hemisphere over the Southern Hemisphere could all be due to tropospheric debris or might be due in one way or another to stratospheric fallout, either by Dr. Machta's theory, or combination of the two.

As we shall see, a study of these soil data, together with recent rain data, indicates that the truth probably lies in a combination of Dr. Martell's theory, Dr. Machta's theory and a part of the author's model.

SOIL DATA, 1958

Figure I presents both the 1956 and 1958 soil data collected from foreign countries by Dr. Alexander in the spring and early summer of both years. The 1958 data show that there was a total deposit of about 25 megatons fission energy equivalent of strontium 90 of which about 18 megatons were in the Northern Hemisphere and 7 megatons in the Southern Hemisphere. Assuming that the stratospheric fallout in the two hemispheres would be symmetrical, my own assumption, I should emphasize, at least for the material injected near the equator, that is for the strontium 90 produced by the United States and the United Kingdom megaton test explosions—as indicated later by direct observation during Operation Hardtack (cf. fig. 2)—an excess of 11 megatons remain in the Northern Hemisphere and the question is whether this can be done to tropospheric fallout from test sites upwind or whether this must be due in part at least either to Dr. Machta's preferential leakage from the stratosphere in this latitude or to Russian polar debris which, according to Dr. Martell, would preferentially settle in the northern latitudes because it would come down in a time so short, 1 year or less, that it would not have had time to spread into the Southern Hemisphere.

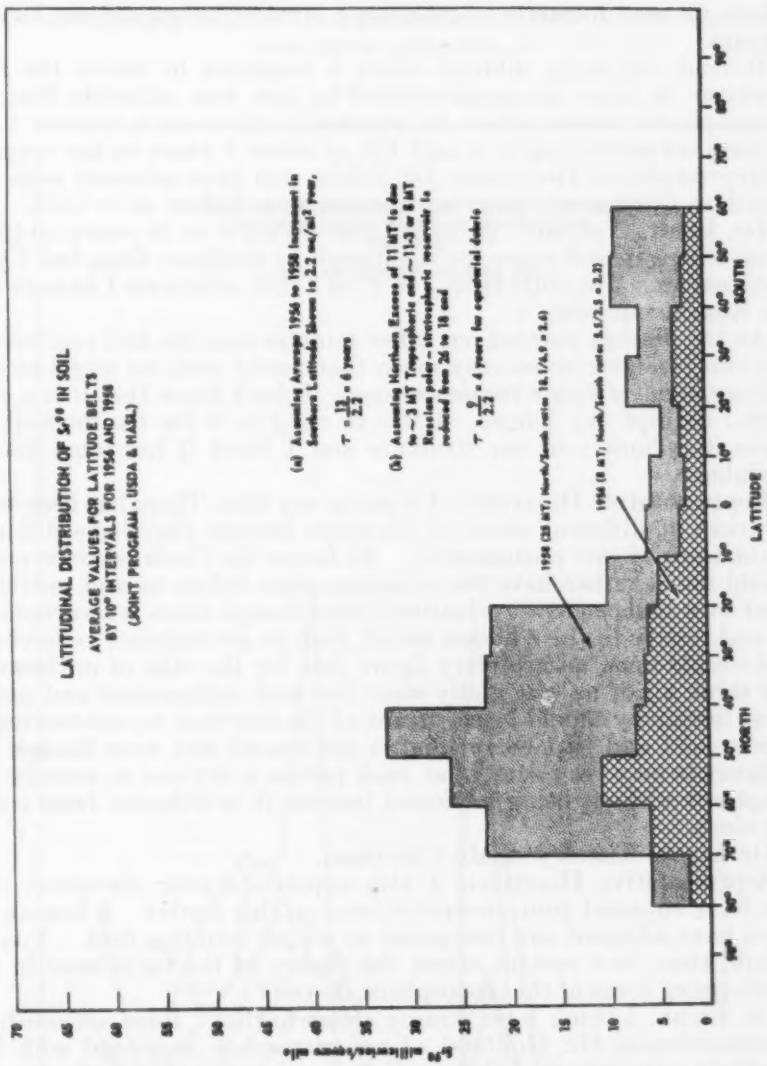

LATITUDINAL DISTRIBUTION OF Sr^{90} IN SOIL
AVERAGE VALUES FOR LATITUDE BELTS
BY 10° INTERVALS FOR 1956 AND 1958
(JOINT PROGRAM - USDA & HASL)
(a) Assuming Average 1956 to 1958 Increment in Southern Latitude Zones is 2.2 mc/mi² per.
$\tau = \frac{1}{2.2} = .5$ years
(b) Assuming Northern Excess of 11 MT is due to ~3 MT Tropospheric and ~11-3 or 8 MT Russian polar-stratospheric reservoir is reduced from 26 to 18 and
$\tau = \frac{8}{2.2} = 4$ years for equatorial debris
1958 (26 MT; North/South ratio 18.1/8.9 = 2.0)
1956 (8 MT; North/South ratio 5.5/2.5 = 2.2)
LATITUDE
NORTH
SOUTH
Sr^{90} millicuries/square mile

FIGURE 1

Anticipating for the moment a result for which we will present evidence in the next section of this paper, namely, that Dr. Martell's theory is essentially correct, one then should subtract from the 11 megatons excess in the spring of 1958 in the Northern Hemisphere approximately 3 megatons estimated tropospheric fallout from the northern latitude test sites to find an excess of some 8 megatons from Russian polar debris.

Now, having removed some 8 megatons of Russian polar stratospheric injection from the general worldwide stratospheric pool of 26 megatons previously assumed, the rate of uniform worldwide fallout observed in the years between 1956 and 1958, 2.2 millicuries per mile, 2 years on the average, is to be compared not with these 26 megatons

which we used formerly to calculate a stratospheric residence time of 6 years.

Instead, one must subtract about 8 megatons to reduce the total reservoir to some 18 megatons and in this way calculate that the stratospheric residence time for equatorial injections is between 4 and 5 years corresponding to a half life of about 3 years on the average.

Representative HOLIFIELD. Dr. Libby, you have adjusted your calculations downward from the time you were before us in 1957.

Dr. LIBBY. Yes, sir. In 1957 I was saying 5 to 10 years, and now I am saying 4 to 5 years for equatorial, as residence time, but 1 year for Russian. The shift from 5 to 10 to 4 to 5, is because I have to pull the Russian out now.

As Dr. Machta pointed out a few minutes ago, the fact you have to use two residence times may mean that pretty soon we ought to quit talking about a single residence time. I don't know that it is a very useful concept any longer. I like to cling to it for the moment because it is built into our structure and I think it has some limited usefulness.

Representative HOLIFIELD. I want to say this: There has been some criticism at different times of scientists because they have different evaluations of this phenomenon. As far as the Chair is concerned, I would much rather have the scientists come before us and testify of their own independent evaluations, even though there is a variance in it, and testify to their honest belief, than to get together beforehand and decide upon an arbitrary figure just for the sake of uniformity.

I think all of us who really want free and independent and unfettered testimony should be cognizant of the fact that we are moving in a new field and that everything is not known and even though the judgments may vary somewhat, each person is entitled to exercise his judgment without being criticized because it is different from someone else's.

Dr. LIBBY. Thank you, Mr. Chairman.

Representative HOLIFIELD. I also appreciate your statement that you have adjusted your viewpoint some on this matter. I know a lot of us have adjusted our viewpoints as we get into this field. You do accept, then, to a certain extent the theory of the turbulence in the overlapping areas of the troposphere, do you?

Dr. LIBBY. I think I am coming closer to that. I am not much of a meteorologist, Mr. Holifield. I am very much impressed with Dr. Machta's meteorological theories. It seems to me they make a great deal of sense. I think the best thing to do is to look closely at the data and just try to move as carefully as we can in keeping with our observations.

Of course, the division of the 11 megatons excess between tropospheric and Russian polar stratospheric injections is somewhat arbitrary, but it does seem likely that something like this division is proper in view of the data and considerations to be presented in the next section.

RUSSIAN OCTOBER FALLOUT IN THE SPRING OF 1959 IN THE MIDDLE NORTHERN LATITUDE

FIGURE 2

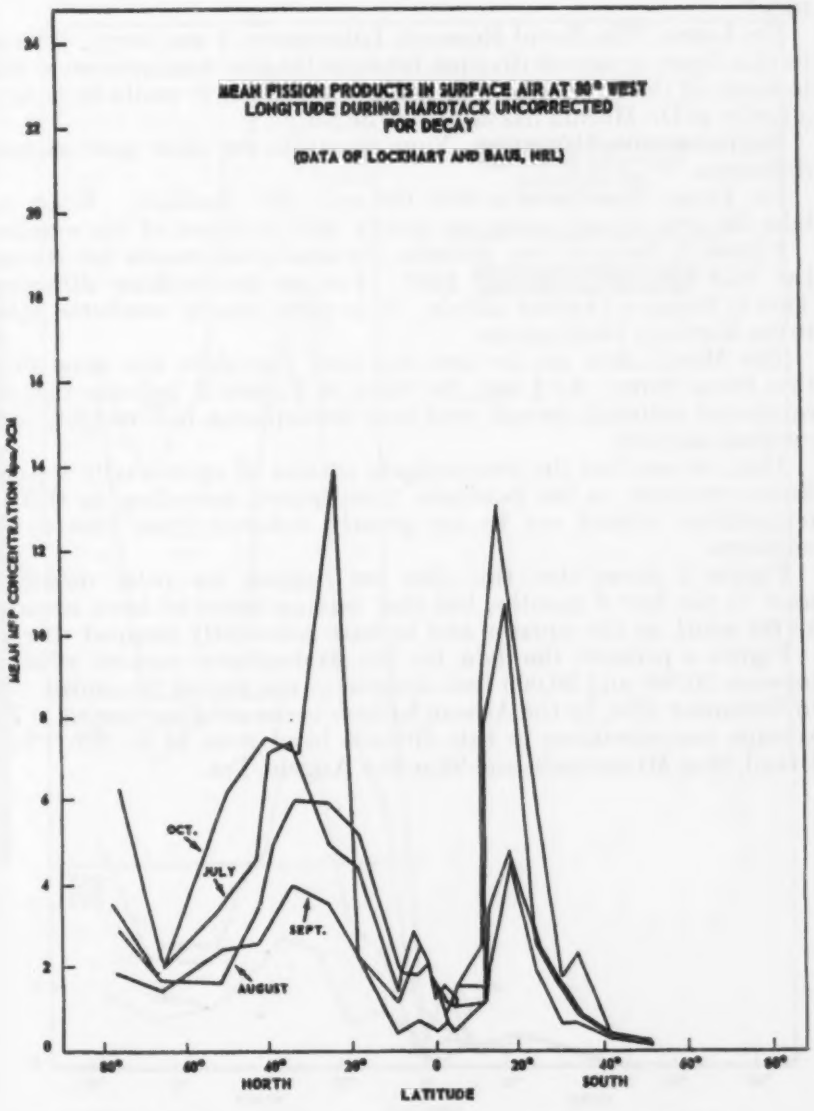


Figure 2 presents the data of the Naval Research Laboratory—L. B. Lockhart and R. A. Baus—on the concentration of radioactive fallout mixed fission products at a variety of positions along the 80th western meridian, for the months in the late summer and early fall of last year when the Pacific operations were being conducted and terminated.

Representative HOLIFIELD. Is that taken from the figures of the Naval Radiological Research Laboratory?

Dr. LIBBY. That is correct.

Representative HOLIFIELD. That is not the Radiological Laboratory?

Dr. LIBBY. The Naval Research Laboratory, I am sorry. You see in this figure a sort of division between the two hemispheres a little in favor of the northern. I do not know whether it would be as large a factor as Dr. Machta has suggested or not.

Representative HOLIFIELD. Your charts do not show quite as much difference.

Dr. LIBBY. You have to take the area, Mr. Holifield. When you take the area it may work out pretty well in terms of his numbers.

Figure 3, the next one, presents the analogous results for November 1958 through February 1959. You see the striking difference. This is Russian October debris. It is quite clearly restricted solely to the Northern Hemisphere.

The March data are in now and they just show the same thing that these show. As I say, the data in Figure 2 indicate that the equatorial material spreads into both hemispheres in a roughly symmetrical manner.

Thus, we see that the stratospheric content of equatorially injected fission products in the Southern Hemisphere, according to this interpretation should not be too greatly different from that in the northern.

Figure 3 shows that this does not happen for polar debris, at least in the first 4 months, but that mixing seems to have occurred as far south as the equator and to have essentially stopped there.

Figure 4 presents the data for the stratospheric content as taken between 50,000 and 90,000 feet altitude in the period November 1956 to November 1958, by the Ashcan balloon-borne air filter project. The average concentrations in this altitude band were 24 at Sao Paulo, Brazil, 26 at Minneapolis and 32 at San Angelo, Tex.

FIGURE 3

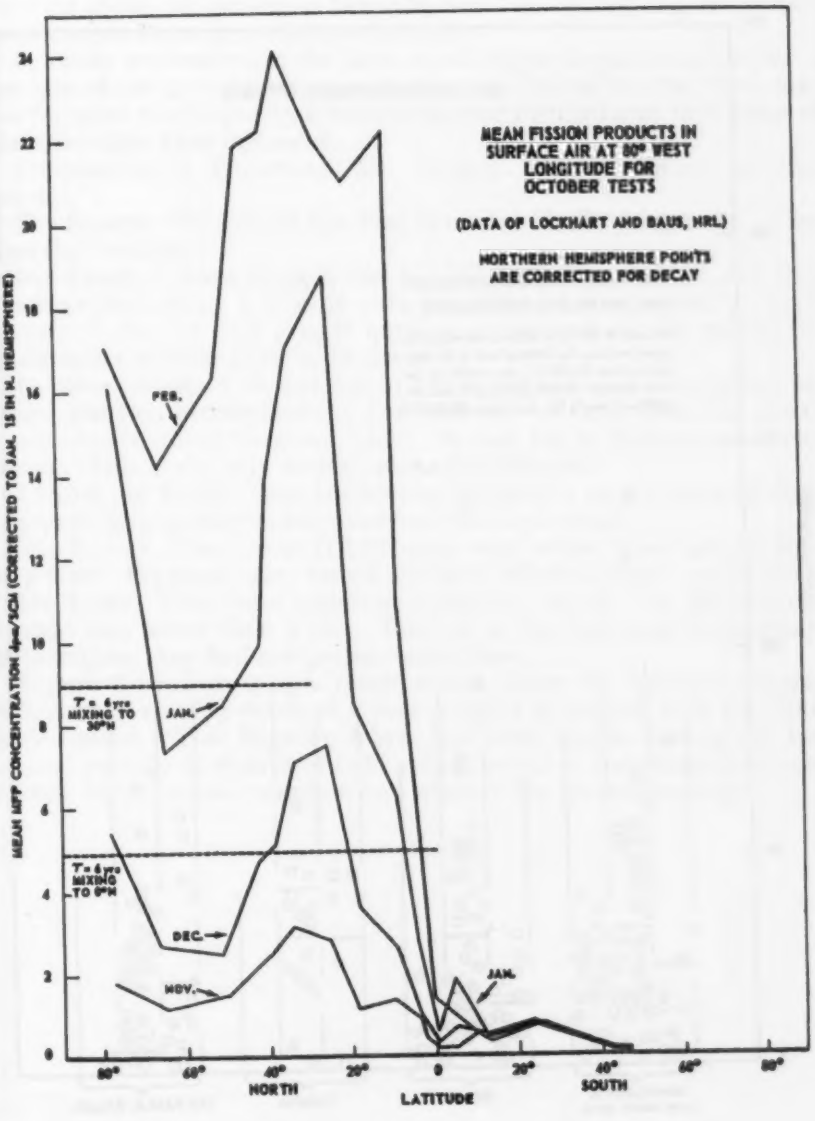
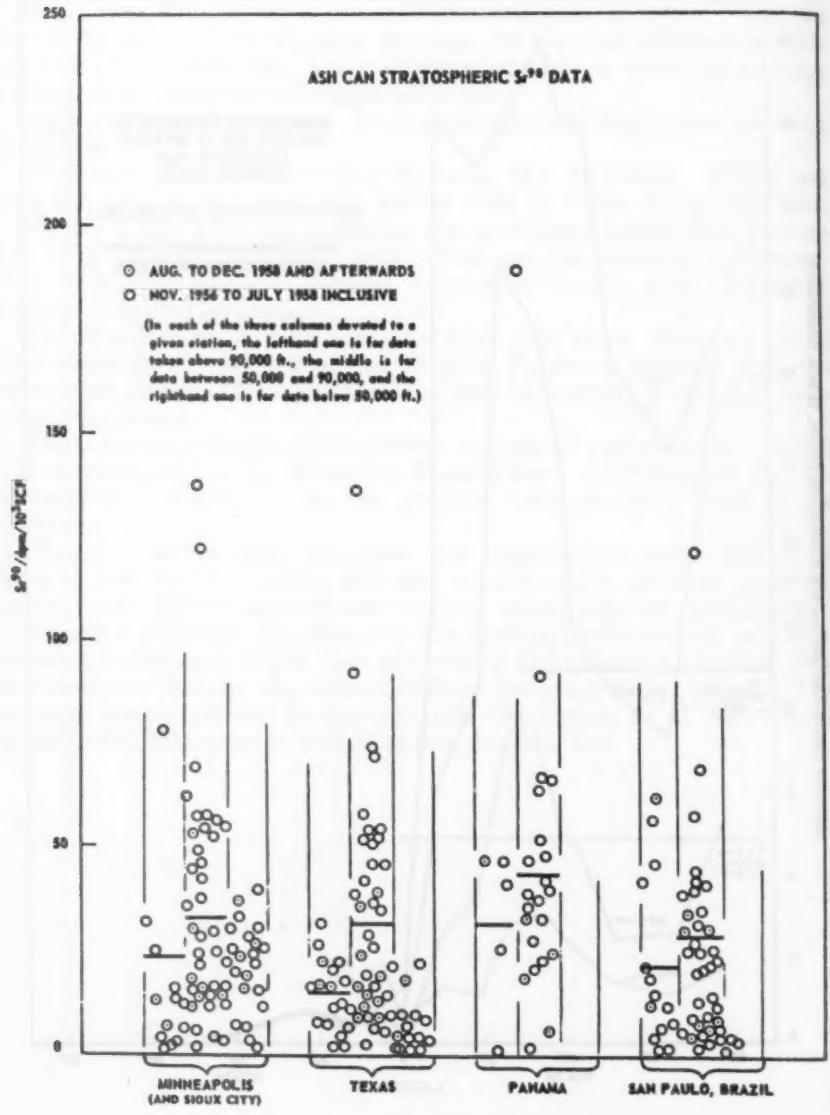

MEAN FISSION PRODUCTS IN SURFACE AIR AT 80° WEST LONGITUDE FOR OCTOBER TESTS
(DATA OF LOCKHART AND BAUS, NRL)
NORTHERN HEMISPHERE POINTS ARE CORRECTED FOR DECAY
MEAN MFP CONCENTRATION 4π/SCM (CORRECTED TO JAN. 15 IN N. HEMISPHERE)
FEB.
JAN.
T = 6 yrs MIXING TO 30°N
DEC.
NOV.
T = 6 yrs MIXING TO 0°N
JAN.
80° 60° 40° 20° 0 20° 40° 60° 80°
NORTH
LATITUDE
SOUTH

FIGURE 4


ASH CAN STRATOSPHERIC Sr⁹⁰ DATA
AUG. TO DEC. 1958 AND AFTERWARDS
NOV. 1956 TO JULY 1958 INCLUSIVE
(In each of the three columns devoted to a given station, the lefthand one is for data taken above 90,000 ft., the middle is for data between 50,000 and 90,000, and the righthand one is for data below 50,000 ft.)
250
200
150
100
50
0
MINNEAPOLIS (AND SIOUX CITY)
TEXAS
PANAMA
SAN PAULO, BRAZIL

I find this crude averaging of all of the data seems to indicate a rather smaller dependence on latitude than Mr. Holland's analysis and Dr. Machta's analysis. I would say that the data themselves have internal weaknesses which we are all aware of and we are very worried about the quality of the data, but I do see nothing in the data which ought to be dependent on latitude.

I can see weaknesses in the data which might depend on altitude. I put this chart up for what it is worth as an indication that there may not be quite the disparity between the two hemispheres that some of the other data have indicated.

Representative HOLIFIELD. Mr. Ramey has a question at that point.

Mr. RAMEY. How about the data from the HASP program? What does this indicate?

Dr. LIBBY. I have studied the HASP data, Mr. Ramey, and they are beautiful data. I wish it were possible to have them in all their detail. I do not find myself quite as convinced of the points Dr. Shelton draws from them as he does.

In other words, I do not see in those data quite the variation between the two hemispheres if you take out of those data the recent bomb clouds which have not had a chance yet to disseminate themselves. This is the only major point of difference.

I think the HASP data are invaluable, and as we get more of them they will help greatly to solve some of these questions.

Mr. RAMEY. The initial HASP data were before these largest Russian tests. So those tests would not have affected them, would they?

Dr. LIBBY. They were rather deficient as I recall. Dr. Shelton can answer this better than I can. That is, in the Southern Hemisphere at that time, they had not gotten down there.

Figure 5 presents a new result which shows the Russian October debris to be coming down at a rate roughly in accord with Dr. Martell's theory. The Russian debris has been visible during the last several months in clear and bold relief; no other tests have been conducted which would interfere and obscure the phenomenology.

FIGURE 5

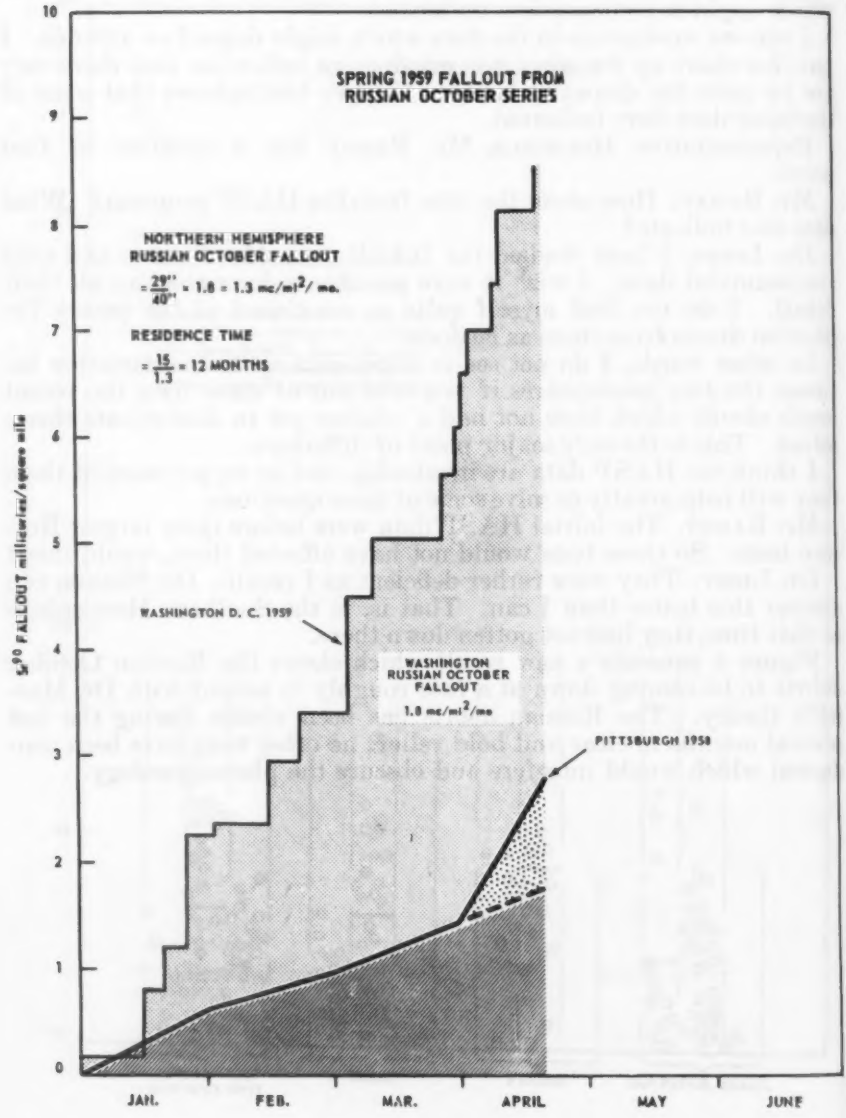


FIGURE 6

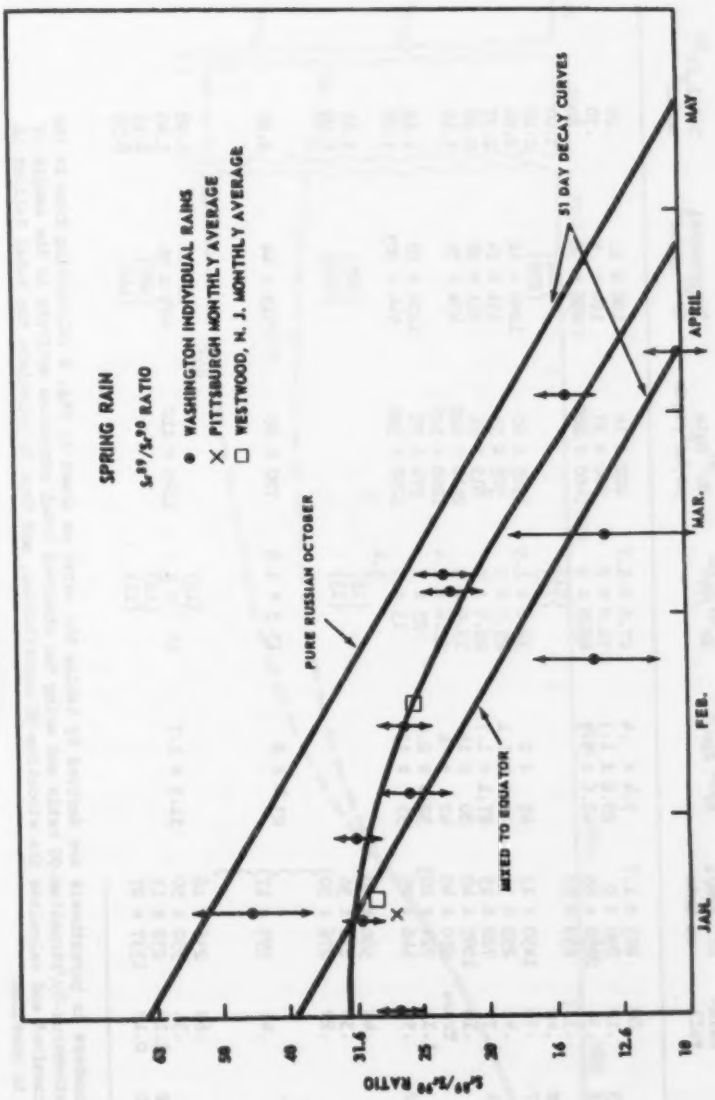

SPRING RAIN
Sr^{89}/Sr^{90} RATIO
● WASHINGTON INDIVIDUAL RAINS
× PITTSBURGH MONTHLY AVERAGE
□ WESTWOOD, N. J. MONTHLY AVERAGE
51 DAY DECAY CURVES
PURE RUSSIAN OCTOBER
MIXED TO EQUATOR
MAY
APRIL
MAR.
FEB.
JAN.
63
50
40
31.6
25
20
16
12.6
10
Sr^{89}/Sr^{90} RATIO

FIGURE 6

TABLE I

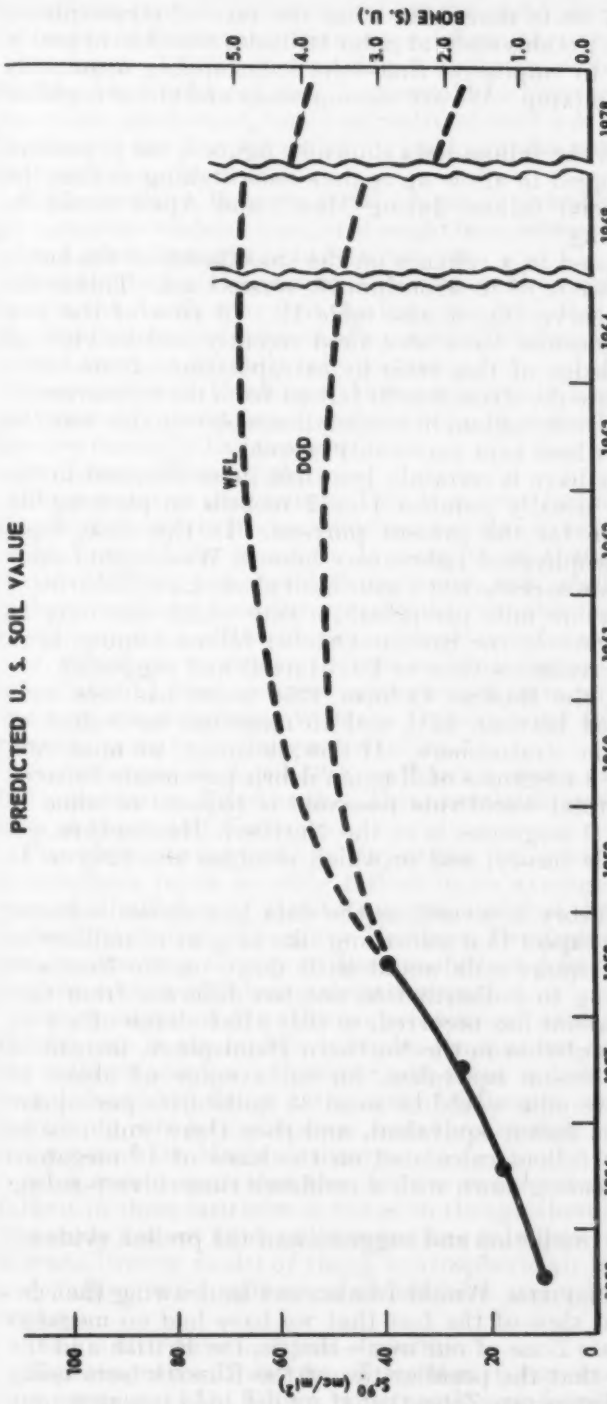
SUMMARY OF WASHINGTON RUSSIAN OCTOBER DATA

Date	Rain-fall	Sr^{89} dpm/l on Date	Sr^{90} dpm/l	Sr^{89}/Sr^{90}	Sr^{90} Rate $\mu c/mi^2$/inch	Incremental Sr^{90} $\mu c/mi^2$	Total Sr^{90} mc/mi^2
Jan. 1	.88	203 ± 1.7	7.4 ± .4	27.6 ± 1.7	222 ± 14	196 ± 11	.20
Jan. 14-15	.12	890 ± 9	28.6 ± 1.3	31.2 ± 2	860 ± 37	104 ± 5	.30
Jan. 15-16	.34	2230 ± 65	48.6 ± 9.3	45.9 ± 9	1460 ± 280	496 ± 96	.80
Jan. 20	.33	639 ± 55		(31)		(202)	1.00
Jan. 21-22	.42			(31)		(202)	1.20
Jan. 26-27	.76	1450 ± 13	45 ± 2	31.8 ± 1.9	1365 ± 60	1040 ± 46	2.24
Feb. 3-4	.43	259 ± 3	10.1 ± 1.1	25.7 ± 3	303 ± 33	131 ± 14	2.37
Feb. 12-14	.75	722 ± 15	27.1 ± 1.7	26.7 ± 2	815 ± 51	611 ± 28	2.98
Feb. 23	.18	1085 ± 40	80 ± 14	13.9 ± 3	2410 ± 420	434 ± 76	3.42
Mar. 4-5	Trace	950 ± 40	42 ± 4	22.6 ± 2.4	1260 ± 126		
Mar. 5-6	1.13	724 ± 203	32.4 ± 2.6	23 ± 2	974 ± 78	1104 ± 88	4.52
Mar. 11-12	.52	446 ± 25	35 ± 13	13 ± 5	1050 ± 390	544 ± 203	5.06
				3.4			
Mar. 27	.44	580 ± 30		(13)		(585)	5.65
Mar. 30	.30	636 ± 36		(13)		(436)	6.09
Apr. 2 6 A.M. to 1:00 P. M.	.29	276 ± 50	23.4 ± 2	15.3 ± 1.3	700 ± 60	519 ± 44	6.60
Apr. 2 1 P.M. to 5 P.M.	.45	397 ± 17					
Apr. 3-4	.69	236 ± 16		(13)		(378)	6.98
Apr. 9-10	.31	550 ± 50	51.5 ± 3.7	10 ± 1	1545 ± 110	479 ± 35	7.46
Apr. 10-12	1.17	232 ± 13		(12)		(688)	8.15
Apr. 19-20	0.12	1337 ± 27		(11)		(440)	8.59

Footnote

The numbers in parenthesis are derived by taking the curve as drawn in Fig. 6 calculating from it the expected strontium-89/strontium-90 ratio and using the observed total strontium activity in the sample of rainfall involved and calculate the strontium-90 contribution, and thus to calculate the total fallout in the storm in question.

PREDICTED U. S. SOIL VALUE


BONE (S. U.)
5.0
4.0
3.0
2.0
1.0
0.0
1978
1968
1964
1963
1962
1961
1960
1959
1958
1957
1956
1955
WFL
DOD
PREDICTED U. S. SOIL VALUE
100
80
60
40
20
0

This has allowed us to determine what the rate of stratospheric fallout from these injections made at polar latitudes and thus to nearly settle—and I want to emphasize that—the longstanding arguments about stratospheric mixing. We are coming closer and closer together all the time.

In order to obtain the fallout data shown in figure 5, the procedure of analysis was changed to allow up-to-date recordtaking so that the extremely high crucial fallout during March and April would be known for this hearing.

The change consisted in a reliance on the smoothness of the curve of the ratio of strontium 89 to strontium 90, versus time. This is the strontium 89 to 90 curve (fig. 6, also table I). In view of the fact that no nuclear explosions have been fired recently and in view of the fact that knowledge of this ratio by extrapolation of the curve allows one to calculate the strontium 90 fallout from the measurement of the total radioactive strontium in a rainfall sample—in this way the data in figure 5, have been kept reasonably current.

The accuracy they have is certainly less than those obtained in the normal way, which usually requires 1 or 2 months in process, but probably is adequate for the present purpose. In this case, these data taken at the Geophysical Laboratory here in Washington show an average fallout rate over the last 4 months of about 2.3 millicuries of strontium 90 per square mile per month, a rate which can only be explained in my opinion by the Russian October fallout coming down with about a 1-year residence time as Dr. Martell had suggested.

As stated earlier, the Russian October 1958 series has been estimated to have added between 12½ and 15 megatons equivalent of fission products to the stratosphere. If now, however, we must subtract something like 8 megatons of Russian debris previously injected in polar shots, the total worldwide reservoir is reduced to some 18 megatons, of which 9 megatons is in the Northern Hemisphere, according to my simple theory, and to which is added the 12½ to 15 megatons.

If Dr. Martell's theory is correct, as the data just shown indicate, one would therefore expect that something like 12½ to 15 millicuries of strontium 90 per square mile would settle down on the Northern Hemisphere according to a distribution not too different from that in which the past fallout has occurred, so that after elapse of a year or so the total accumulation in the Northern Hemisphere, instead of being 18 megatons fission equivalent for an average of about 18 millicuries per square mile would be some 33 millicuries per square mile, or 33 megatons fission equivalent, and then there would be in addition to this the fallout calculated on the basis of 18 megatons spread worldwide, coming down with a residence time corresponding to 4 or 5 years.

This would be the prediction and suggestion of the present evidence as I see it.

Representative HOLIFIELD. Would I be correct in drawing the conclusion, then, that in view of the fact that we have had no megaton tests in the Temperate Zone of our own—that is, the British and the United States—and that the peculiarities of the Russian tests being to the north of the Temperate Zone, that if we did hold megaton tests

in the Temperate Zone we might have the rapid precipitation, or would the height of the troposphere cause a different type of fallout?

Dr. LIBBY. I think that we do not really know the answer. I think Dr. Machta would say yes, there would be shorter residence time as you move northward, but you really should ask him that question. It seems to me that we really do not know the answer as to whether this would happen or not.

Representative HOLIFIELD. Of course, if it would be true that you get a shorter residence time, or it might be in between——

Dr. LIBBY. It might be in between; yes.

Representative HOLIFIELD. The tests in the South Pacific and the tests in the Arctic zone that the Russians held, this would have a very significant meaning in terms of a potential nuclear war.

Dr. LIBBY. It certainly is important.

Representative HOLIFIELD. Because it would mean that you would get your concentration of radioactivity in a shorter period of years than we normally had thought.

Dr. LIBBY. That is right.

Representative HOLIFIELD. This is a new factor of hazard to the people of the world in case a nuclear war should take place.

Dr. LIBBY. That is right. It seems to me that going to the model of Dr. Machta, you would expect some such gradation off from the highest residence time for equatorial to the shortest at the poles. As I say, I am not a meteorologist. I have to defer to him on that.

If, therefore, we assume that polar debris stays airborne on the average of about 1 year, one now must go back through the rainfall curves and note the correlation with the Russian polar injections. The correlation seems to be quite satisfactory.

For example, in April 1958, as figure 5 shows, there is a rise in the fall out rate in Pittsburgh. This correlates well with the Russian tests at the end of February.

Therefore, we suggest that injections made near the poles into the stratosphere result in early fallout in an average period of about 1 year or a half time of about 8 months, and that the large hump in the latitudinal distribution in the Northern Hemisphere in foreign countries is due very largely to Russian fallout from the polar tests, the total up to mid-1958 being about 8 megatons.

The question of Dr. Machta's theory of extrarapid stratospheric fallout rate in the middle latitudes remains not completely settled in the author's opinion. However, one point is certainly clear from the data I showed in figure 1, the rate of fallout in equatorial latitudes is less than it is in latitudes away from the Equator—and this is an essential point of Dr. Machta's theory.

So it would seem that this feature is correct and that the rate of fallout in these latitudes is less even though therainfall there is high. The early fallout from polar injections is in general keeping with the Machta-Brewer model of rising stratospheric air in equatorial regions and falling stratospheric air elsewhere and particularly, in polar regions.

That is all I have to say on strontium.

Representative HOLIFIELD. I wonder if you would read again the first paragraph, Dr. Libby, underneath your introduction. I want to say that the networks have shown a great interest in this matter and

in discussion with some of my colleagues on the committee, we felt that it was in the public interest to get as much of this information as possible while it is current to the people, and the networks have promised considerable time to take this information to the people.

Of course, we realize that our hearings do not have the popular distribution that a newsreel has.

Your biggest disagreement at this time, then, Dr. Libby, in the material that is put before us seems to be in the level of fallout for the Southern Hemisphere and the Northern.

Dr. LIBBY. That is right. And also the residence time. I would point out to you that we are down to a factor of two or somewhat less in difference on that estimate. As we will see in the discussion tomorrow morning, I believe, Mr. Holifield, the difference at this time is getting to be more of scientific interest than it is of substantial matter. We had a little seminar yesterday bringing this out, and we had no trouble agreeing that, considering the uncertainties, we can buy 30–30–30. That is, 90 megatons total fission, 30 local, 30 upstairs, and 30 down. The uncertainties in all of our various theories are such that we can buy this. Though we still conduct these discussions, I think it should be made clear that we are getting close enough so that the argument is getting to be more of scientific interest than general public interest.

Representative HOLIFIELD. I might say before you read the first paragraph, we will have a panel discussion on this tomorrow morning, and this will be gone into in some detail.

Dr. LIBBY. You want the first paragraph?

Representative HOLIFIELD. Will you read the first paragraph of your introduction?

Dr. LIBBY. The intensive series of bomb tests fired by the U.S.S.R. during last October affords a unique opportunity to test whether stratospheric radioactive fallout from injections made at polar latitudes differs appreciably in distribution or fallout rates from that due to equatorial explosions, such as the United States and United Kingdom have fired. The Russian October series is estimated on the basis of assumptions previously described, to have added about 12.5 to 15 megatons equivalent of fission products to the stratosphere, whereas the previous inventory on the same basis was about 25 to 30 megatons equivalent so the Russian addition amounted to a sudden increase of about 50 percent and, as we shall see later, this, on the basis of later information, probably is low, the most likely figure being 80 percent.

Representative HOLIFIELD. This is a very significant point in these hearings to bring out, that is, the fact that the Russian tests are depositing faster and hotter fissionable material on the people of the world than the U.S. tests. I do not say this in any other manner than saying that it seems to be a scientific fact, and of course the radioactivity that is deposited from our own tests is equally deleterious, if there be a deleterious factor in it.

Are there any further questions of Dr. Libby on his testimony?

Dr. LIBBY. I would introduce this last section on bomb C–14 in the record. It was something I thought you might want in the record.

Representative HOLIFIELD. That will be accepted and the charts you used will also be printed in the record.

(The material submitted by Dr. Libby follows:)

IV. BOMB CARBON-14

As pointed out earlier[1] the neutrons escaping from a nuclear device during a nuclear explosion in air will make carbon-14 almost quantitatively just as the cosmic ray produced neutrons do in the natural radiocarbon genesis. As stated previously, as of January 1, 1958, an estimated 10^{28} carbon-14 atoms had been injected into the atmosphere, mostly in the stratosphere. The present total figure should be higher in approximate proportion to the total estimated yields. This is to be compared with a normal stratospheric carbon-14 content of about 9×10^{27} carbon-14 atoms so the stratospheric carbon-14 content should have been about doubled.

Data on the rise in carbon-14 content of the troposphere and living matter are given in Figures 7 and 8 and the recent literature.[5-12]

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5 / Suess, Hans, "Radioactivity of the Atmosphere and Hydrosphere," Annual Review of Nuclear Science, 8, 243 (1958).

6 / Broecker, Wallace S. and Walton, Alan, "Radiocarbon from Nuclear Tests," Science. (To be published)

7 / DeVries, H. A., "Atom Bomb Effect: Variation of Radiocarbon in Plants, Shells and Snails in the Past Four Years," Science, 128 250 (1958).

8 / Munnich, K. O. and Vogel, J. C., "Durch Atomexplosionen Erzeugter Radiokohlenstoss in der Atmosphare," Naturwissenschaften, 45, 327 (1958).

9 / Suess, Hans, "Low Level Counting," Progress Report on Contract No. AT(11-1)-34, Project 10, August 1958.

10 / Rafter, T. A. and Fergusson, G. J., "Atom Bomb Effect -- Recent Increase in the Carbon-14 Content of the Atmosphere, Biosphere and Surface Water of the Oceans," New Zealand J. Sci. Technol. B 38, 871 (1957). "Atom Bomb Effect"-- Recent Increase of Carbon-14 Content of the Atmosphere and Biosphere," Science, 126, 557 (1957); and Second U. N. Int. Conf. on Peaceful Uses of Atomic Energy, A/Conf. 15/P/2128, New Zealand (1958).

11/ Fergusson, G. J., "Reduction of Atmospheric Radiocarbon Concentration by Fossil Fuel Carbon Dioxide and the Mean Life of Carbon Dioxide in the Atmosphere," Proc. Roy. Soc. (London) A 243, 561 (1958).

12 / Brannon, H. R., Jr., Daughtry, A. C., Perry, D., Whitaker, W. W., and Williams, M., Trans. Am. Geophys. Union 38, 643 (1957).

From these it is clear that the carbon-14 descent from the stratosphere is not out of keeping with a residence time of several years, possibly five, although our knowledge of the stratospheric reservoir content is imperfect.

The similarity between the rises observed in the Northern and Southern Hemispheres suggest a short latitudinal mixing time of the order of two years or less as pointed out by Fergusson[11] with the fossil fuel CO_2 effect, and Broecker and Walton[6] with the bomb carbon-14. The estimate of the amount by which bomb carbon-14 will raise the general carbon-14 level when complete mixing with the oceans has occurred has risen from 0.3 to about 0.4 or 0.5 percent now due to the firings during 1958.

Of course, in the short time range before the deep ocean mixes, the concentration of radiocarbon in the biosphere will rise as the stratospheric material descends. If the total exchangeable carbon reservoir in the top layer of the ocean and the troposphere and biosphere is X times that in the stratosphere and the present carbon-14 increase in the stratosphere is say 200 percent, then we must expect 200/X percent as the eventual increase in the troposphere, biosphere and top ocean. Since X is about 14 we should then expect an increase of about 14 percent which would last for several years. If the mixing with the top ocean is slow relative to the mixing of the atmosphere there may be a rise above this value for a few years after which it will settle back and gradually, over a matter of several centuries, fall to the 0.4 to 0.5 percent value, depending on the time required to mix with the deep ocean. Subsequent to this it will decay with its 5600 year half-life.

The movement of the bomb carbon-14 should help considerably in solving the remaining mysteries of atmospheric mixing patterns and storage times.

Several points about the biological effects of this carbon-14 have been made in recent publications.[13-14-15]

13/ Leipunsky, O. I., "The Radiation Hazards of Ordinary Explosions of Pure Hydrogen and Ordinary Atomic Bombs," Atomnaya Energ. 3, 530, (1957).

14/ Pauling, Linus, "Genetic and Somatic Effects of Carbon-14," Science, 128, 1183 (1958).

15/ Totter, J. R., Zelle, M. R., Hollister, H., "Hazards to Man of Carbon-14," Science, 128, 1490 (1958).

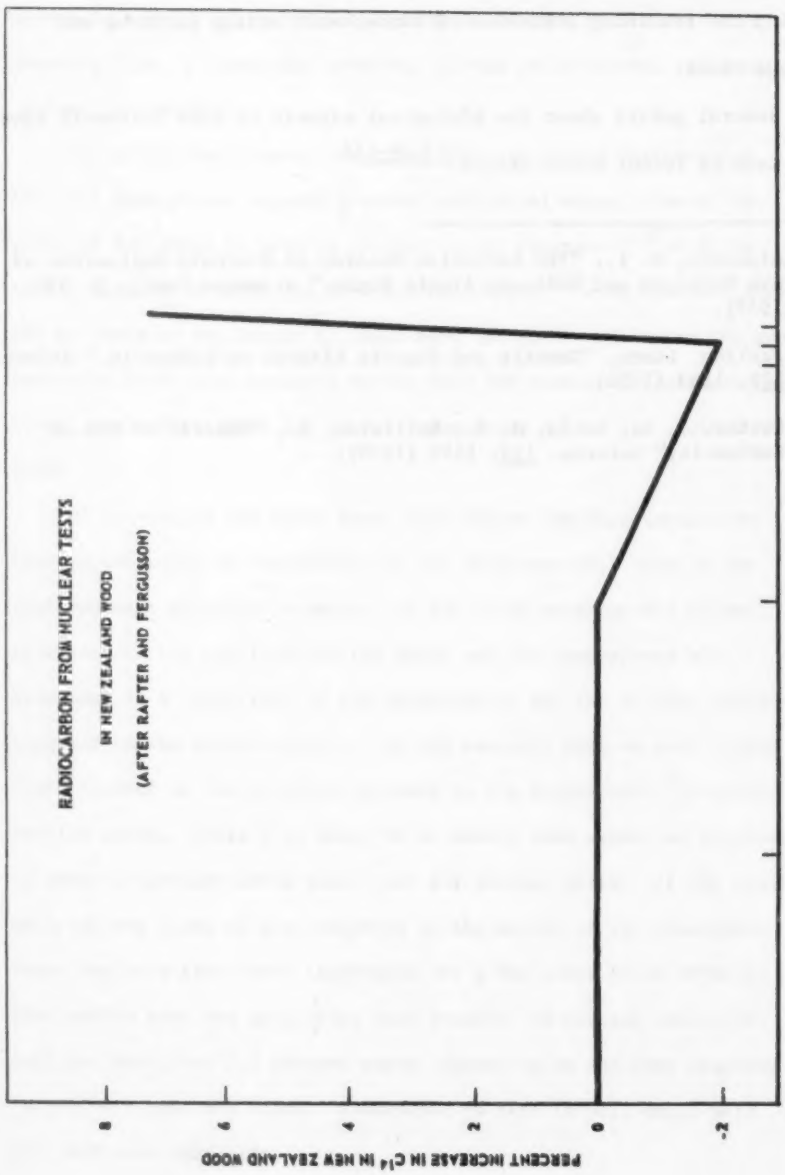
RADIOCARBON FROM NUCLEAR TESTS
IN NEW ZEALAND WOOD
(AFTER RAFTER AND FERGUSSON)
PERCENT INCREASE IN C14 IN NEW ZEALAND WOOD
8
6
4
2
0
-2
1880
1890
1900
1950
1953
1954
DATE

Figure 7

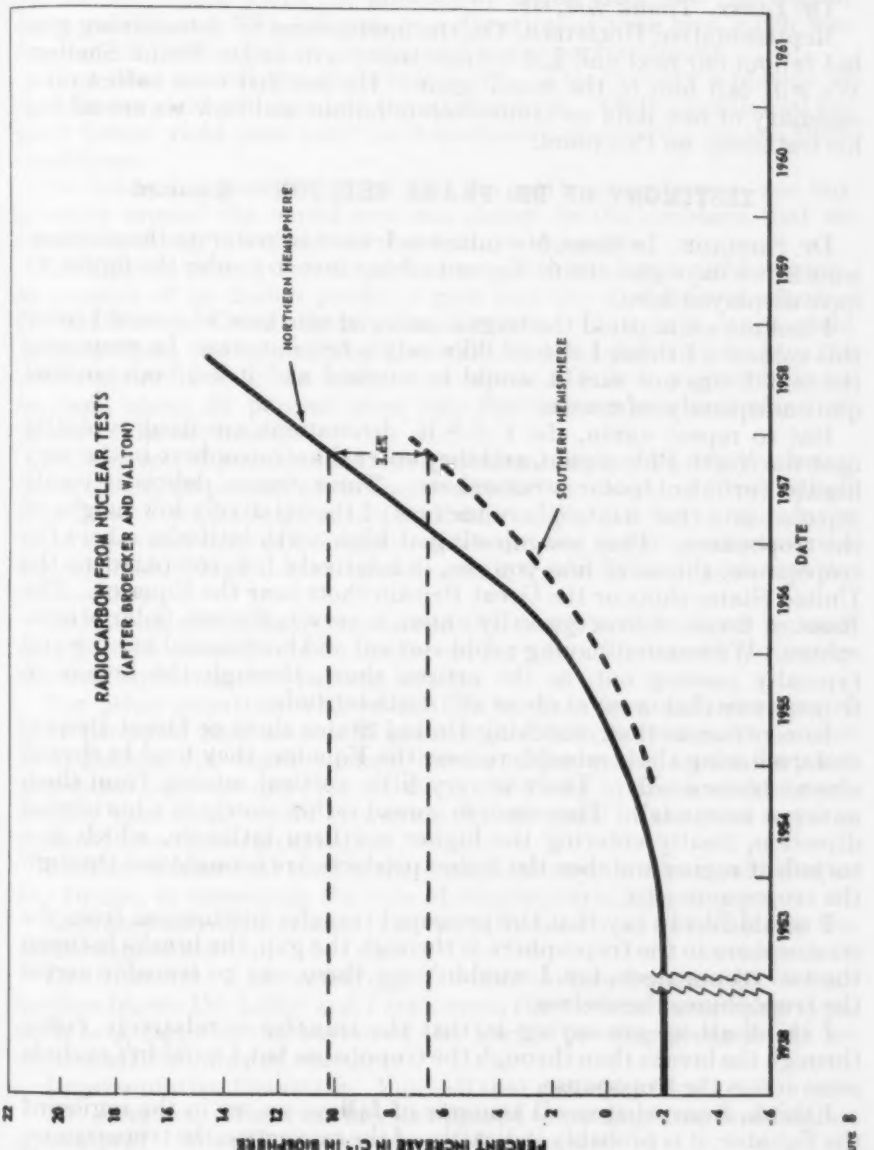
RADIOCARBON FROM NUCLEAR TESTS
(AFTER BROECKER AND WALTON)
NORTHERN HEMISPHERE
SOUTHERN HEMISPHERE
3.4‰
PERCENT INCREASE IN C14 IN BIOSPHERE
DATE
1961
1960
1959
1958
1957
1956
1955
1954
1953
1938
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6

Figure 8

Representative HOLIFIELD. Thank you, sir.

Dr. LIBBY. Thank you, sir.

Representative HOLIFIELD. On the mechanisms of determining global fallout our next and last witness today will be Dr. Frank Shelton. We will call him to the stand again. He testified once before on a summary of new data on atmosphereic fallout and now we are asking his testimony on this point.

TESTIMONY OF DR. FRANK SHELTON [1]—Resumed

Dr. SHELTON. In these few minutes I want to reiterate the mechanisms as we have seen them: figure 1 of my text to you or the figure we have displayed here.

I had not anticipated the large number of speakers who would cover this subject. I think I should take only a few minutes. In preparing the text I was not sure it would be covered and it has been covered quite adequately, of course.

But to repeat again, the U.S.S.R. detonations are fired typically near the North Pole region, and they enter the stratosphere in the very highly turbulent polar stratosphere. Their fission debris is easily injected into that stratosphere because of the relatively low height of the tropopause. They are injecting at high north latitudes where the tropopause, the solid line you see, is relatively low compared to the United States shots or the Great Britain shots near the Equator. The Russian fission debris typically enters a very turbulent polar stratosphere. We watch it having rapid vertical and hortizontal mixing and typically passing out, as the arrows show, through the breaks in tropopauses that occur at about 40° north latitude.

In contrast to that, watching United States shots or Great Britain shots, entering the stratosphere near the Equator, they tend to spread almost horizontally. There is very little vertical mixing from them as far as we can tell. They seem to spread rather slowly in a horizontal direction, finally entering the higher northern latitudes, which is a turbulent region and then the fission products are brought out through the tropopause gap.

I would like to say that the principal transfer mechanism from the stratosphere to the troposphere is through the gap, the breaks between the two tropopauses, but I wouldn't say there was no transfer across the tropopauses themselves.

I think all we are saying is, that the transfer is relatively faster through the breaks than through the tropopause but I wouldn't exclude some across the tropopause.

I think, from what small amounts of fallout we see in the region of the Equator, it is probably indicative of the rate across the tropopauses. It is not real simple. One should not be categorical and say it is all through the gaps. I think it is just faster through the gaps.

I had only one other statement to make on the mechanisms. To make the data that have been made available to us the most useful that they can be, I would like to refer to the previously declassified AEC material on the shots. In particular table 3 of these data will prove to be extremely useful to other scientists throughout the country, not

[1] See biographical sketch, p. 763.

only this country but others, because notice in table 3 we tell you, versus the various years, the kilotons of fission yield as a function of burst conditions. We tell you as a function of time how much was fired as air bursts, surface bursts, and water surface bursts.

That does not tell you the whole story. There is only a portion of that fission yield which enters the stratosphere. Only a portion of the total fission yield goes into the stratosphere, depending on the burst conditions.

Dr. Libby has provided in his text the partitioning factors, and any scientist around the world now can almost do the problems that we have been doing in a classified way in these last years.

Looking at table 3 for the airbursts: If it is a large yield weapon, 99 percent of its fission products goes into the stratosphere whether United States, Great Britain, or Russian. If it is a large yield weapon about 99—or you might as well say 100—percent goes into the stratosphere if it is an airburst weapon. If it is a ground-burst weapon, about 20 percent goes into the stratosphere and about 80 percent falls out locally.

So, you see, if you conduct testing as land surface bursts, you bring down locally 80 percent of the fission products created. I think indeed that is why we have gone to the Pacific. We can fire certain large yield shots and only put one-fifth of the created fission products in the stratosphere. Had it been an airburst, it would have all gone into the stratosphere.

Dr. Libby and I have considered the water-surface burst in some detail. His numbers are on the record for you. He uses 80 percent in the stratosphere and 20 percent locally.

For other scientists who would like to do it in a different way, I have proposed that we use 30 percent in the stratosphere, 70 percent local fallout for water surface bursts. Maybe the actual fact lies someplace between our two. I think for those in the scientific community that these would represent the extremes in the total amount injected into the stratosphere.

I believe that would clarify the record for anyone who would like, in the future, to recompute the rate of stratospheric injection.

Representative HOLIFIELD. You actually have very little data on the underwater tests?

Dr. SHELTON. I am referring to water-surface bursts. By water-surface bursts Dr. Libby and I both mean the surface-water burst type, such as a barge in the lagoon of the Pacific proving grounds—as we conducted a number of our shots.

Representative HOLIFIELD. You call that a surface?

Dr. SHELTON. Water surface as opposed to putting it on real land or a coral reef. We call that a water-surface burst.

Representative HOLIFIELD. That is what we have always called an underwater test. The test of July 26, 1946, was submerged, as I remember.

Dr. SHELTON. You are perfectly correct for that one. But the great bulk of Pacific testing by the United States has been detonations on barges out on the surface of the water in the lagoon of the particular atoll concerned.

Representative HOLIFIELD. I was speaking of the July 26, 1946, test at Bikini.

Dr. SHELTON. Yes; that was definitely underwater. That is not typical of the bulk of our testing. I believe that clarifies, as far as I can, the record for mechanisms of injections.

No. 1, I think anybody can now repeat, generally, the mechanisms and the amounts of fission products which have been injected into the stratosphere. No. 2, we have told you how much is on the ground now. One can then compute rough residence times. I think it is available now to the scientific community to compute residence times. I have given you the ingredients.

No. 3, we have said the mechanism by which it is coming out of the stratosphere.

Representative HOLIFIELD. Thank you very much.

I have a statement on global fallout, by Merrill Eisenbud, which I would like to place in the record at this point.

(The statement referred to follows:)

DEPOSITION OF STRONTIUM-90 THROUGH OCTOBER 1958

Prepared by Merril Eisenbud,
Manager, New York Operations Office,
U. S. Atomic Energy Commission

SUMMARY

It is estimated that the global deposition of strontium-90 increased from 1.9 to 2.6 megacuries during the period from June 1957 to October 1958. During this time the stratospheric reservoir of strontium-90 increased from 1.4 to 4.3 megacuries. Approximately 90% of the deposition of debris now stored in the stratosphere will have occurred by 1970.

In 1958, the strontium-90 content of powdered milk in the New York area averaged 5.9 μμc per gram of calcium in comparison with 3.9 μμc per gram of calcium for the previous year. For this region of the country, the strontium-90 content of milk appears to be increasing in proportion to the strontium-90 content of the soils from which the cows derive their forage.

For the record of the Hearings on "Fallout from Nuclear Weapons Tests" conducted by the Joint Committee on Atomic Energy, Washington, D. C. during the week of May 5, 1959.

42165 O—59—vol. 1——58

The upper limit of foreseeable contamination in milk can be estimated by assuming that this proportionality will continue until all of the strontium-90 has been deposited from the upper atmosphere. This procedure should yield estimates which tend to err on the side of safety. In this manner, it is estimated that the maximum foreseeable sustained level of milk contamination in the New York area is 11 μμc per gram of calcium. A child deriving its calcium from dairy sources may be expected to develop a skeleton having 5.5 μμc per gram of calcium. This estimate is double that made in June 1957 and reflects the increased stratospheric inventory due to USSR detonations in 1958.

The radiological dose to the skeleton from natural sources such as cosmic rays, radium potassium, etc., is approximately 125 mrem per year. A skeletal burden of 5.5 μμc Sr-90 per gram of calcium will deliver a dose of approximately 5.5 mrem per year to the bone marrow. The maximum foreseeable dose from strontium-90 in the New York area is thereby estimated to be about 5% of the dose due to natural radioactivity.

DEPOSITION OF STRONTIUM-90 THROUGH OCTOBER 1958

This article is intended to update previous reports (1,2) in which the present and future global deposition of strontium-90 were discussed in relation to the contamination of foods and deposition in the skeleton of man.

The accumulation of fallout in various parts of the world continues to be documented by the methods described earlier. The oldest method is that of the network of gummed films, which was initiated in 1952 and which permits daily observations of the rate and accumulation of fallout at a great many locations in the United States and abroad. In addition, beginning in 1955, soil samples have been collected annually from a number of locations and have been analyzed radiochemically for strontium-90 (3). A third method is the collection of deposited or precipitated dust in pots. Such sampling was begun by the United States in early 1954, and the program now includes 41 stations in the United States and elsewhere (4).

Although it is the most difficult of the three methods, radiochemical analysis of soil is the best indicator of possible human hazard in that it is a direct measure of the

strontium-90 potentially available for introduction to biological processes. However, for some purposes it is desirable to know not only how much strontium-90 has accumulated in the soil at any given time but what is the fallout rate over a given period of time. The use of pots or gummed film is convenient for this purpose.

A serious limitation to the use of gummed films is the fact that the amount of strontium-90 is not determined directly but is computed from a measurement of total beta activity. This computation requires access to classified information concerning the dates and size of nuclear detonations (5). Until June 1957, estimates of cumulative strontium-90 fallout based on gummed film data were in approximate agreement with estimates obtained from direct radiochemical analyses of samples collected in pots. Fig. 1, which has been developed from published data (5,6), illustrates the comparative data at that time.

Previous articles (5,7) have called attention to the increasing difficulty of estimating the strontium-90 content of the radioactivity collected by the gummed films. During late 1957 and for the first ten months of 1958, the tempo of testing was such that the mixtures of tropospheric and stratospheric debris of various ages and in uncertain ratios greatly increased the difficulty of calculating the

strontium-90 component from the estimated age of the total beta activity. For this reason, the estimates of strontium-90 from gummed film measurements have not been continued beyond June 1957. The loss of this source of information has been offset by the fact that the network of monthly pot collections has been expanded greatly since 1957. In addition, an excellent set of soil samples has been collected by the Department of Agriculture at 76 localities in 36 countries.

The data of the gummed-film network for the years 1955 through 1957 are plotted together with the results of the 1958 soil analyses in Fig. 2. The gummed film data for the United States and the islands of the Trust territories of the western Pacific were excluded from this figure because the deposition pattern in these areas is affected primarily by local meteorological factors and the location of the testing grounds. For example, the winds in the western part of the United States are such that the strontium-90 deposition at San Francisco, to the northwest of the Nevada proving grounds, was 11 millicuries per square mile in mid-1957 compared to 54 millicuries per square mile at Salt Lake City, located at a comparable distance to the northeast. This difference, which is due entirely to the pattern of the prevailing winds, would mask the less pronounced variations which are attributable to other factors at greater distances from the sites of detonations.

The data for all soil samples collected by the Department of Agriculture (8) are included but the results from 4 samples collected in Oahu have been averaged and included as a single value so as to not unduly weigh the average value for the band at 20-30° North.

The fallout pattern is shown to have varied systematically with latitude during the three years since 1956, but the relatively high North Temperate Zone values were not evident in 1955. The latitudinal variation for the latter three years proves to be in agreement with the work of Stewart et al. (9) in the United Kingdom, and tends to support the suggestion first made by Stewart and his colleagues that the global pattern of strontium-90 deposition is influenced by the manner in which stratospheric-tropospheric exchange takes place. Citing the model of the exchange mechanism advanced by Brewer (10), Stewart noted that radioactive debris injected into the stratosphere should deposit preferentially in the North Temperate Zone.

It has been noted by others that the North Temperate Zone of maximum deposition coincides with the latitudes in which much of the testing has occurred and that the relatively high deposition values may therefore result from the fallout of tropospheric debris. A strong argument against this possibility is that the 1958 cumulative

deposition in the 30-70° North Latitude band is about 1.5 megacuries. If all of the tropospheric debris of United States and USSR origin was deposited in this band, this would only account for a maximum of 25% of the observed amount. In view of the fact that some of the debris was known to be deposited out of the 30-70° band, one can conclude that stratospheric debris accounts for more than 75% of the observed deposition. This is consistent with the estimate of 80% made by the author in 1956 (2).

The areas under the deposition curves may be integrated to yield approximations of the global fallout of strontium-90. The values thus obtained are .59, 1.1, 1.9 and 2.3 megacuries, respectively, for each of the four years of observations. The estimates for 1955 and 1956 are revised from earlier estimates of 1.0 and 1.5 megacuries (1,2).

The cumulative estimates through 1957 are calculated from measurements of total beta activity (5). However, a correction previously used (7) on the basis of earlier comparisons of soil analysis with gummed-film estimates has been eliminated in view of the more recent comparative data (5).

There has been increased emphasis on stratospheric sampling for strontium-90 both in the United States and abroad. However, data from these studies are as yet preliminary, and one must continue to depend on estimates derived

from material balance studies. The starting point in this calculation utilizes classified data of the yields of the individual detonations and estimates of the fraction of the debris that deposits initially in the vicinity of the detonation. The total amount of strontium-90 distributed in the atmosphere can then be apportioned between the troposphere and stratosphere. This apportionment depends on the energy released in the detonation, the height of burst, and meteorological factors.

The author originally estimated the stratospheric inventory in September 1955 to have been 3.0 megacuries (1). A value of 2.0 megacuries now appears to have been more reasonable. The inventory was estimated to be 1.8 megacuries in June 1956 (2) and again in June 1957, indicating that the stratospheric burden remained essentially unchanged during that period. As Libby has previously noted (11), the debris injected into the stratosphere apparently compensated for the deposition that took place during those years.

Although global data on the soil content of strontium-90 do not exist beyond the period of collections in early 1958, it is of interest to extrapolate the observed depositions to November 1, 1958, at which time the suspension of weapons tests took effect. One observes, that the increase

in global deposition between June 1957 and April 1958 was 0.4 megacuries, or 0.04 megacuries per month. Assuming that this rate continued until the end of October 1958, one may estimate the global deposition to have been 2.6 megacuries of strontium-90 at that time.

In order to estimate the maximum future deposition from strontium-90, it is assumed that the debris now stored in the stratosphere will deposit on earth in approximately the same pattern observed in the Spring of 1958. It is estimated that 6.4 megacuries of strontium-90 were injected into the stratosphere by all detonations up to October 31, 1958. Of the 2.6 megacuries deposited globally, 20% is assumed to be of tropospheric origin. We have thus accounted for 2.1 of the original 6.4 megacuries, leaving an estimated stratospheric reservoir of 4.3 megacuries.

The ultimate global deposition may thus be estimated as the 6.4 megacuries originally injected to the stratosphere plus 0.5 megacuries of tropospheric origin. This totals 6.9 megacuries from which one must subtract the 25% which will have decayed in the next ten years, by which time over 90% of the debris will have been deposited. This is based on the estimate that approximately 50% of the stratospheric debris is eliminated every 3 years (12). Thus, the deposit on earth will reach approximately 5 megacuries, roughly twice the levels observed in 1958.

In the United States and other western countries at least half of the calcium deposited in the skeletons of human beings through adolescence originates from dairy products. Milk has therefore been used as one basis (1) for estimating the concentration of strontium-90 which may be expected in human skeletons that reach equilibrium with a strontium-90 contaminated environment.

The Atomic Energy Commission and the U. S. Public Health Service have been analyzing milk from a number of areas in this country and abroad for various periods of time since 1954 (3,13). The concentration of strontium-90 during the last quarter of 1958 is given in Table 1, which also indicates when sampling at each location first began. It is seen that in recent months the concentration of strontium-90 in milk varied from 4.2 to 20 μμc per gram of calcium at the locations sampled.

Estimates of the future exposure of human beings to strontium-90 may be based on the assumption that over a period of several months the average concentration of strontium-90 in milk is directly proportional to the strontium-90 in the soil in which the cow's forage is grown. Estimates made in this way are apt to err on the high side, because one thus ignores absorption due to foliar deposition of strontium-90. Moreover, this assumption implies that

the isotope, once deposited in soil, remains fixed in the root zone of the forage from which the cows derive their nourishment.

In New York state, for which area data are available for the years since 1954, a coarse proportionality between the concentration of strontium-90 in soil and in milk is demonstrated in Fig. 3. The soil values are derived from radiochemical analyses of soils collected annually at Rochester and Binghamton, New York.

Should the trend shown in Fig. 3 continue, the strontium-90 content of milk can be expected to increase when the strontium-90 now stored in the stratosphere deposits on the earth. From our previous estimate of the stratospheric inventory in late 1958, it follows that if the pattern of future deposition is similar to the geographic pattern of the past, the strontium-90 concentration in both the soil and milk of New York may be expected to double in the years to come.

The milk from New York state contained an average of 5.9 μμc of Sr-90 per gram of calcium during 1958. It can be anticipated that the milk in this area may eventually rise to 11 μμc of Sr-90 per gram of calcium from tests conducted up to November 1958. Values of about three times this level would define the upper limit for other areas in the United States.

As noted previously, the proportionality discussed above will not apply if strontium-90 is leached from the root zone over a period of years. That such leaching does occur is suggested by soil analyses which have shown that during the past three years increasing proportions of strontium-90 have been found in the lower levels (3). Estimates of future contamination of foods based on the assumption that strontium-90 is retained in the upper few inches of soil may, over a period of decades, yield estimates which will possibly err on the side of safety.

If, however, we assume that the strontium-90 will remain fixed in the root zones of forage, the only mechanism for diminishing the strontium-90 content of milk will be radioactive decay. Children who are born at the point of maximum soil deposition and who derive their calcium from dairy products, will, for all practical purposes, form a skeleton which is in equilibrium with the strontium-90 contamination of the environment from which their food is derived. Comar (14) has shown that skeletons formed from milk diets contain about 0.5 times the strontium-calcium ratio of the original milk. With this discrimination against strontium, human skeletons formed from dairy products in the northeastern United States could reach a maximum of 5.5 μμc of Sr-90 per gram of calcium.

Actual measurements of strontium-90 in human bone have been undertaken by Kulp (15) during the past several years. In 1957-1958 bones of children in the one to 2-year age group contain 1.8 μμc of Sr-90 per gram of calcium. His work demonstrated that the values observed in human beings are consistent with the observed levels of strontium-90 currently found in food.

This is the fourth consecutive year in which it has been possible to make estimates of the maximum foreseeable skeletal contamination for dairy diets in the New York area. The data for these four years are summarized in Table 2. It may be seen from these data that the forecast values have increased markedly during the past year, due in a large measure to the heavy test schedule of the USSR.

The estimates of future strontium-90 contamination of milk and bone are believed to be conservative estimates of the upper limits of maximum sustained contamination in the New York area. In view of the fact that this mode of computation ignores foliar deposition, and because there is no provision for possible removal of strontium-90 from the soil by natural means other than decay, it is expected that the observed values will in fact be lower than those forecast. On the other hand, during, and for some months following actual testing, excursions above the forecast levels may be

expected in view of the fact that some measure of foliar deposition of strontium-90 is known to occur during such periods.

The United Nations Scientific Committee on the Effects of Atomic Radiation calculated (16) that 1 μμc Sr-90 per gram of calcium is equivalent to a dose of 1 mrem per year to the bone marrow. An individual having 5.5 μμc Sr-90 per gram of calcium in his skeleton will therefore receive a dose of 5.5 mrem per year in addition to the dose from natural radiation of cosmic and terrestrial origin. According to the United Nations Scientific Committee, skeletal irradiation from natural sources is 125 mrem per year. The 5.5 μμc Sr-90 per gram of calcium will therefore increases the natural dose to the bone marrow by about 5%.

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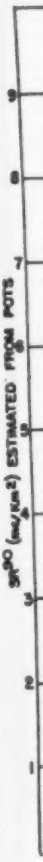

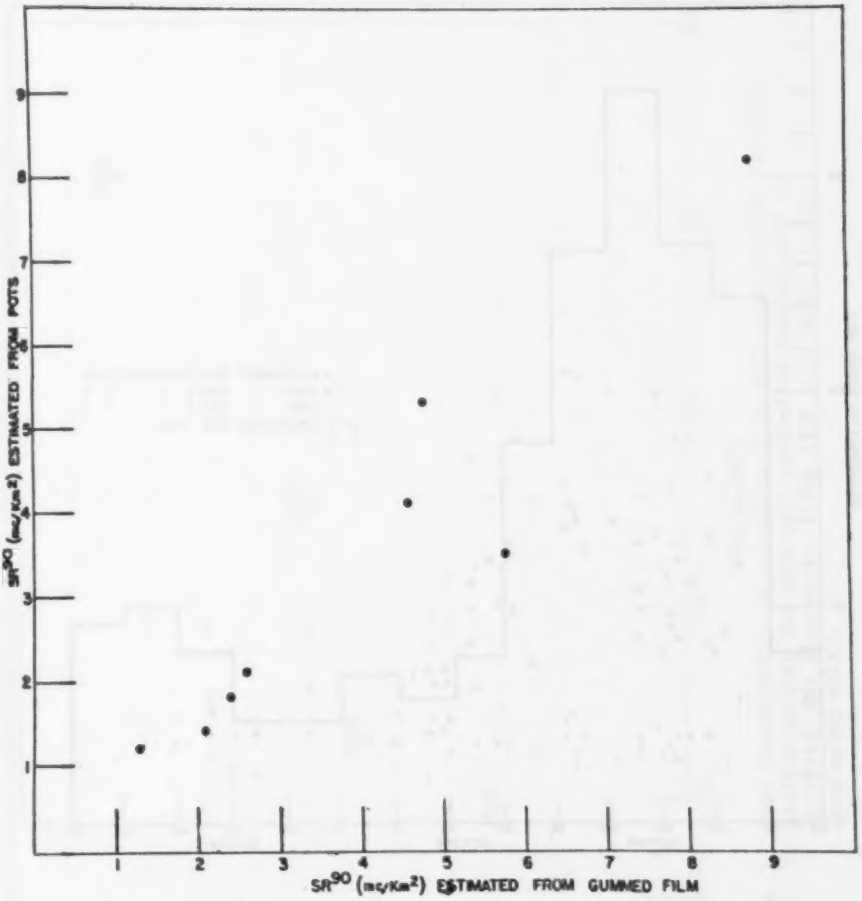

FIG. 1. Comparison of cumulative deposition of strontium-90 at various places as estimated from pot and gummed film samples.

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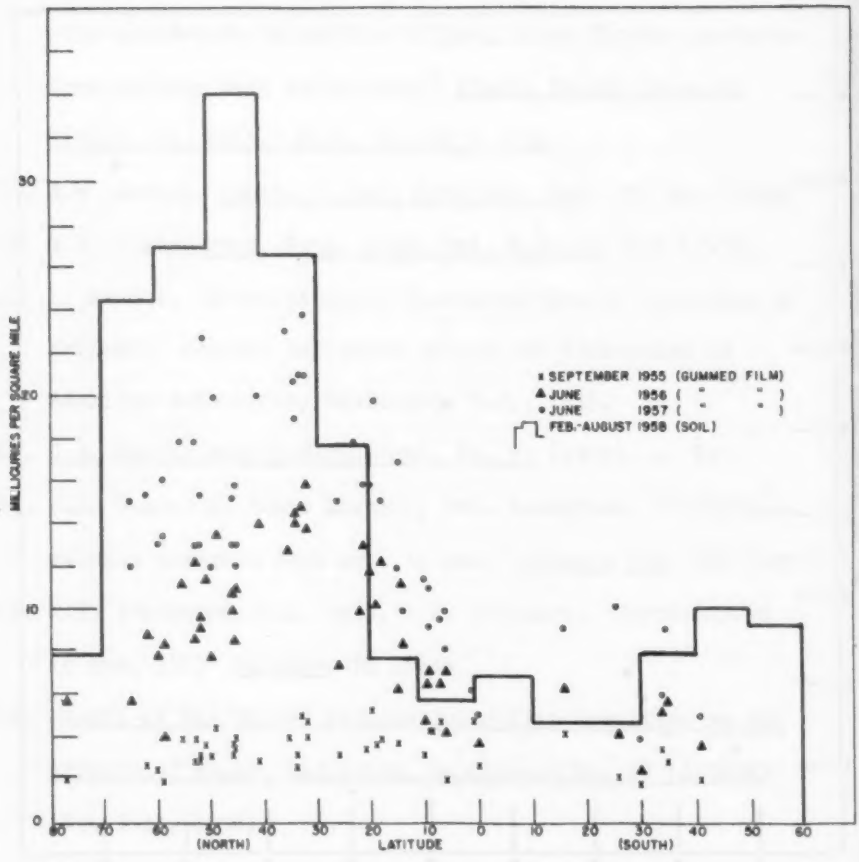

FIG. 2. Estimates of cumulative strontium-90 deposition as a function of latitude for 1955–1959.

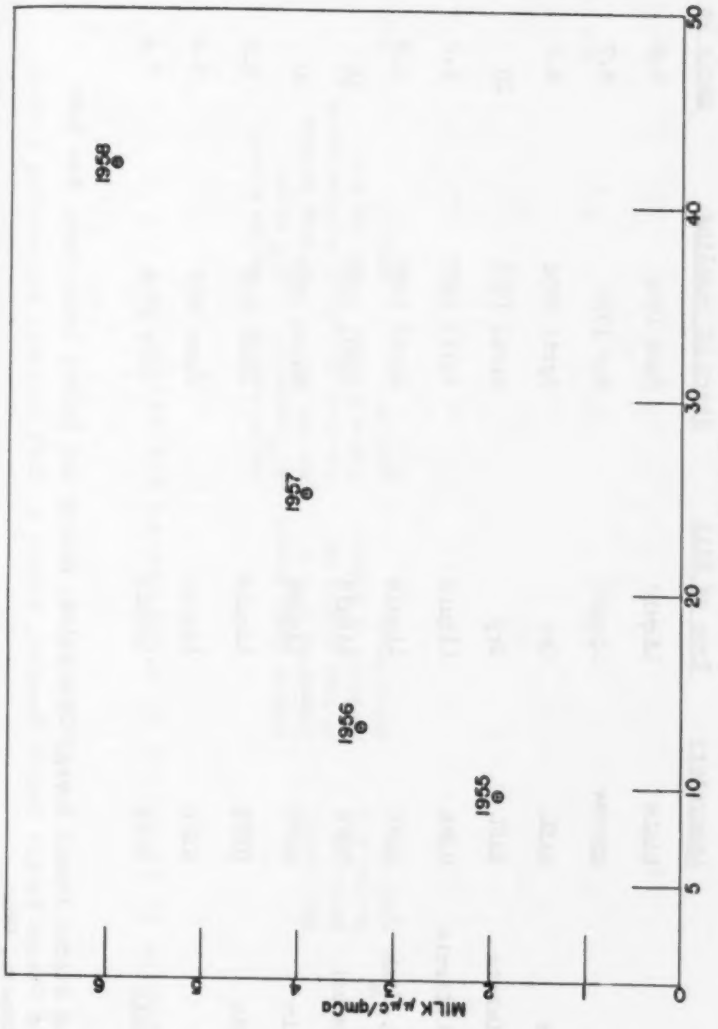

FIG. 3. Mean concentration of strontium-90 in milk from Western New York plotted against the mean soil content of strontium-90 at Rochester and Binghamton. (The 1958 soil value is for Binghamton only).

TABLE 1

CONCENTRATION OF Sr^{90} IN COW'S MILK DURING FINAL THREE MONTHS OF 1958

Place	Laboratory	Type of Milk	Start of Sampling	μμc/g Ca
New York City	HASL*	Liquid	June 1954	9.8
New York City	USPH**	Liquid	May 1957	8.7
Perry, New York	HASL	Dry	April 1954	8.2
Mandan, North Dakota	HASL	Dry	April 1955	20
Sacramento, California	USPH	Liquid	April 1957	4.2
Salt Lake City, Utah	USPH	Liquid	April 1957	4.8
St. Louis, Missouri	USPH	Liquid	April 1957	16
Cincinnati, Ohio	USPH	Liquid	March 1957	10
Atlanta, Georgia	USPH	Liquid	June 1958	8.8
Austin, Texas	USPH	Liquid	June 1958	3.8
Chicago, Illinois	USPH	Liquid	July 1958	7.4

*HASL - United States Atomic Energy Commission, Health and Safety Laboratory, New York
**USPH - United States Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio

**USPH = United States Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio

TABLE 2

SUMMARY OF ESTIMATES OF STRONTIUM-90 CONTAMINATION

Time of Estimate	Cumulative Global Fallout Megacuries Sr^{90}	Stratosphere Reservoir Megacuries Sr^{90}	Strontium-90 Content of New York Milk μμc/g Ca*	Expected Global Deposit (Megacuries Sr^{90}) in 10 Years Assuming 90% Deposition of Stratospheric Debris	Maximum Expected Sr^{90} Content of New York Milk From Tests Prior to Time of Estimate μμc/g Ca	Maximum Expected Sr^{90} Content of Human Skeleton in Equilibrium with New York Milk μμc/g Ca	Reference
Sept 1955	0.6	1.9	1.9	1.7	5.5	2.8	9
June 1956	1.1	1.8	3.3	2.0	6.0	3.0	10
June 1957	1.9	1.8	3.9	2.6	5.3	2.7	This Report
Oct. 1958	2.6	4.3	5.9	4.9	11.0	5.5	This Report

*Mean of Monthly Values for Calendar Year

Representative HOLIFIELD. For tomorrow morning the Chair will announce there will be a roundtable beginning at 10 o'clock: Dr. Langham, Dr. Machta, Dr. Martell, Dr. Libby, Mr. Merril Eisenbud, Mr. Hal Hollister, who was a staff member and consultant 2 years ago, Mr. Joshua Holland, and Dr. Frank Shelton.

Following that roundtable on global fallout we will have a summary of new data on uptake in milk, food, and human bone.

As witnesses we will have Dr. Wright Langham from Los Alamos and Dr. Straub from the Taft Sanitary Engineering Center of the Public Health Service of Cincinnati. I will announce the afternoon witnesses later.

The meeting is adjourned.

(Whereupon, at 5:10 p.m., Tuesday, May 5, 1959, the hearing in the above entitled matter was recessed, to be resumed at 10 a.m., on the following day.)

FALLOUT FROM NUCLEAR WEAPONS TESTS

WEDNESDAY, MAY 6, 1959

CONGRESS OF THE UNITED STATES,
SPECIAL SUBCOMMITTEE ON RADIATION,
JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D.C.

The subcommittee met, pursuant to recess, at 10 a.m., in room P–63, the Capitol, Hon. Chet Holifield (chairman of the subcommittee) presiding.

Present: Representatives Holifield, Durham, Price, Aspinall, Van Zandt, Westland, and Bates; Senators Anderson (chairman of the full committee), Gore, and Aiken.

Also present: James T. Ramey, executive director; John T. Conway, assistant director; George E. Brown, Jr., and George F. Murphy, professional staff members; Richard T. Lunger, technical adviser; and Dr. Paul Tompkins, committee consultant, Joint Committee on Atomic Energy.

Representative HOLIFIELD. The committee will be in order.

This is the second day of public hearings by the Subcommittee on Fallout in Nuclear Weapons Tests. Yesterday the committee received presentations by the AEC and Public Health Service on their programs, and in the afternoon we received presentations on global fallout.

We will begin this morning's session by having a roundtable on the global fallout question; several of whom presented testimony on the subject yesterday will be included in the panel, and some additions. They are: Dr. Wright Langham, Dr. Lester Machta, Dr. E. A. Martell, Dr. Willard F. Libby, Mr. Merril Eisenbud, Mr. Hal Hollister, Mr. Joshua Holland, and Dr. Frank Shelton.

I think it would be helpful this morning if we would begin by having some member of the roundtable participants briefly summarize the main points emerging from the presentations yesterday, and then we will launch into questions on major differences of opinion.

As you know, 2 years ago when we ended our hearings there were quite a number of areas of difference of opinion and more areas on unknown material. Since that time there has been some agreement on the controversial positions, and there has been an increase in knowledge. So we will start out with the summary.

ROUNDTABLE DISCUSSION ON GLOBAL FALLOUT. PARTICIPANTS: DR. WRIGHT LANGHAM, DR. LESTER MACHTA, DR. E. A. MARTELL, DR. WILLARD F. LIBBY, MERRIL EISENBUD, HAL HOLLISTER, JOSHUA HOLLAND, AND DR. FRANK SHELTON

Dr. LIBBY. Mr. Eisenbud will summarize.

Mr. EISENBUD. I believe, Mr. Chairman, that the scientists themselves believe there is a considerable measure of agreement, and that any disagreement that does exist involves details of mechanisms rather than matters which would grossly affect the conclusions one derives from the various data that have been submitted. An important conclusion from yesterday's presentations was that much useful information now exists. The data have been derived, very largely, in the last 2 years by expansion of programs already existing in 1957, but which had at that time only begun to develop useful information.

It is now clear that nonuniform circulation of stratospheric debris between the hemispheres is a characteristic of fallout. The essential point here is that there is agreement as to the mechanism which produces the observed differences in fallout that were first reported 2 years ago. At the 1957 hearings it was noted that the fallout levels in the Northern Hemisphere were higher than those in the Southern Hemisphere. The ratio of the two values was not too different from what is being reported today. There has always been agreement that this different exists. I think that we are now in agreement as to the mechanism that produced the differences in fallout pattern.

Representative DURHAM. Why is that?

Mr. EISENBUD. The fallout patterns in the Northern Hemisphere are related to the discontinuities in the tropopause. It is through this slot in the base of the stratosphere that the fallout diffuses down into the lower atmosphere. Because this slot is located at about 40° north latitude, one therefore would expect that at 40° north latitude the Northern Hemisphere fallout would be highest.

Representative DURHAM. That will continue to be true over the years to come.

Mr. EISENBUD. Presumably so, sir.

Representative DURHAM. If that theory is correct.

Mr. EISENBUD. There are a number of other points. It is generally agreed that the residence time in the stratosphere is shorter than had been believed hitherto. I think here it is important to point out that as a result of the inherent form of the various models that the various scientists in this country and abroad have adopted for the purpose of forecasting future strontium 90 levels, the residence time in the stratosphere is not related to the long-range hazard from strontium 90.

For example, the most authoritative forecast was that made by the United Nations about a year ago. In that calculation, the maximum strontium 90 in human bone in the years to come was proportionately related to the stratospheric residence time. If the stratosphere residence time was 10 years, then the hazard as computed by the United Nations' mode of computation was roughly twice that if the residence time was 5 years.

Chairman ANDERSON. You mean the shortening of the residence time we are now encountering means that the amount of strontium going into the human bones is much higher than we formerly thought?

Mr. EISENBUD. By one mode of computation——

Chairman ANDERSON. By 1 or 2 or 3 or 5 or 10 times?

Mr. EISENBUD. I am sorry; maybe I got your question backward.

Chairman ANDERSON. We have recently discovered that the rate of fallout is much greater than people were saying some years ago. They said 7 years, 10 years. Then they got it down to 4 years and 2 years. Does that mean that more strontium 90 is deposited in individuals or less?

Mr. EISENBUD. Ultimately less, because this means that by assuming a longer residence time, we have overestimated the stratospheric inventory. If, as we now find to be the case, the residence time is less than we thought it was, then the amount of strontium 90 in the stratosphere is less than we thought from the older model.

Chairman ANDERSON. Mr. Eisenbud, we had some testimony at one time about how good it was and it stayed up there, and it came down gradually. Now we get testimony about how good it is and it comes down fast and does not stay up very long. What should a man believe, in your opinion?

Mr. EISENBUD. You mean with respect to this particular question?

Chairman ANDERSON. Yes. One time it is good because it stays up for 10 years. That is wonderful. The next time it is good because it comes down in 2 years, that is wonderful. Which would you believe?

Mr. EISENBUD. I have been asked to summarize what the panel submitted yesterday.

Chairman ANDERSON. I asked you what you thought, Mr. Eisenbud.

Mr. EISENBUD. I think it has been clear from the very beginning that the stratospheric residence time is short in relation to the radiological half life of strontium 90. This means that for purposes of computation one can neglect the residence time and simply assume that it is all going to come down. Everything that goes up has to come down.

Chairman ANDERSON. Now you are on a physics law that I can understand. What goes up must come down. Does that apply also to these claims about how it does no damage and what goes up must come down?

Mr. EISENBUD. No one has ever suggested that it was going to stay up so long that all the strontium 90 would decay and, therefore, would not be a problem to mankind.

Chairman ANDERSON. No one?

Mr. EISENBUD. No, sir.

Chairman ANDERSON. I thought I read some statements about how there was a natural rate of decay of strontium 90, and that it decayed out at certain speeds and, therefore, by staying up there was decaying.

Mr. EISENBUD. The strontium 90 in the stratosphere decays at the rate of 2.5 percent a year. This means if it stays up there 10 years, 25 percent will decay.

Chairman ANDERSON. Wouldn't that be good? You say it comes down faster; it is bad. If it stays up there and decays, isn't that good? That is what they told us 5 years ago. Everybody knew it was good because it was going to stay up so long it would decay out.

Dr. Langham, for whom I have the greatest respect, gave me a whole new slant. He says we don't want to put it up there faster than it decays. I agreed with him, as he well remembers, because that seemed to be a most sensible point of view.

Now, when it comes down faster, how does that change our situation? Doesn't that stop the decay out of the atmosphere?

Mr. EISENBUD. Yes. It makes a change of the order of perhaps 10 or 15 percent.

Representative HOLIFIELD. I think the point needs to be clarified here, and it might take the blackboard to do it. We have been measuring the fallout at the rate of, let us say, x amount per year. If we predict that there will be $10x$ over a 10-year period, and we suddenly find that it comes down in 4 years, that would mean that there would be $4x$ total in place of $10x$ total. I am using round figures because there would be the decay minus what would occur during the 10-year period. So when you say that it comes down faster, that does not necessarily change the figures statistically which we have observed in the amount that has come down in the first year and the second year. It merely means that you are getting closer to the end of the total fallout than we originally thought. Is that a fairly clear statement?

Mr. EISENBUD. Yes, sir; I think that is clear. What we are saying, in effect, is that the big uncertainty that could be in error by as much as several hundred percent has always been the amount of strontium 90 in the stratosphere. I have before me the United Nations report, with which you are all familiar. This problem came up repeatedly during the 2½-year period during which this report was being developed. The committee was confronted with alternate hypotheses of 5-year and 10-year residence times, corresponding to 3-year and 7-year half times. Computations were made of the 70-year bone dose for both the 10- and 5-year residence times, first assuming a 10-year residence time. The dose to population is in the one case almost twice what it was in the other. The high dose was from the computation which assumed the 10-year residence time. The smaller dose was from the computation which assumed the 5-year residence time.

Again the big difference came because by assuming that the residence time is shorter, we conclude that we have previously overestimated what is in the bank upstairs. This is a big difference, a much larger difference than the one in the other direction, due to the fact that less decay time occurs. In the one case there is a factor of 100 percent. In the other case it is a factor of 15 percent. That, Mr. Anderson, is the clearest I can make it.

Chairman ANDERSON. Thank you, Mr. Eisenbud.

Representative DURHAM. Do you think those figures are very accurate as far as the storage amount in the upper stratosphere is concerned?

Mr. EISENBUD. If I might defer that question until tomorrow, a group of us have been meeting on this question in an attempt to define the outer limits of this estimate, and therefore the range of uncertainty that exists. I would prefer that these computations be deferred.

Representative DURHAM. I think it is an important question. If we can be assured that the figures given us are fairly correct, it would be helpful.

Representative HOLIFIELD. We will ask tomorrow the range of variance of opinion, and then what is a reasonable judgment of a compromise level when you do testify on this subject at length tomorrow.

Mr. EISENBUD. Yes. It is quite clear, Mr. Chairman, that this is one of the many factors of the problem about which there is less uncertainty. The total of estimates is between 54 and 65 megatons of injection into the stratosphere. Since the range was that narrow, we have decided to use 60 megatons for purposes of computation.

Representative HOLIFIELD. Before you go from 2.2 in your outline there, will you explain the reason for Martell's exception of 5 to 10 years residence time for Castle debris. Is that significant? Should we know that particular test is accepted as giving possibilities of a longer range?

Mr. EISENBUD. It is my personal view, sir, that this is one aspect of Dr. Martell's testimony about which for the time being we should be cautious, but that one reasonable assumption which would explain his finding is that the Castle yields were so large that the cloud heights were very much higher and subject to less diffusion in the stratosphere.

Representative HOLIFIELD. The size of the weapon actually projected higher into the stratosphere?

Mr. EISENBUD. Yes, sir.

Representative HOLIFIELD. Proceed, please.

Mr. EISENBUD. I will skip over the outline to what I believe are the more substantive points in view of the passage of time.

The Northern Hemisphere peak is more than twice the Southern Hemisphere peak because Russian debris appears to be coming down only in the Northern Hemisphere, and virtually all tropospheric fallout is in the Northern Hemisphere. This is a rather remarkable finding of the past year, which I think is not only of scientific importance but does alter our concept of the deposition of fallout from nuclear weapons, particularly in the event of nuclear war.

Fallout levels on the ground in the United States have approximately doubled since 1956. I might add, on the basis of data which also came out yesterday, that the size of the stratospheric inventory is such that we may expect that the ground levels will again double during the next 2 to 5 years, as a result of deposition of debris now stored in the upper atmosphere.

The deposition in the United States is higher than the deposition in the other countries at the same latitude.

Representative HOLIFIELD. We can assume that the doubling will occur even if there be no more atmospheric tests?

Mr. EISENBUD. Yes, sir. There continue to be differences in estimates of stratospheric residence time, but it is significant, I think, that these differences now cover a narrower range than was true 2 years ago. It is my own view that of the various theories presented yesterday the two that at first sight seem to be furthest apart might be the Martell theory as applied to Russian debris and Dr. Machta's theory. In my own view, the two sets of conclusions are completely consistent. One can reconcile Dr. Martell's observations on the basis

of Dr. Machta's theory by simply noting that the Russion detonations have occurred closer to the discontinuity in the stratosphere, and that therefore less diffusion and dilution takes place by the time the Russian debris hits the slot and begins to diffuse down to earth.

One of the complications which has not as yet been resolved is that there has been a coincidence in time between the various test detonations and a rise in the rate of fallout in the spring months. Some of us believe that this rise is due to the fact that testing has been in progress during the spring months. Others believe that this rise is due to the upper atmosphere transport mechanisms as outlined by Dr. Machta. We are in agreement that this increase takes place. We disagree as to the mechanism which produces it. But this does not alter the fact that the increased deposition in the spring months has occurred consistently since 1954.

One conclusion inherent in Dr. Martell's finding of a shorter residence time for Russian debris is that the short-lived gamma emitting isotopes do not have as much time to decay before they fall out. We may therefore expect the gamma dose from Russian debris to be higher than would be the case if the detonations occurred in more southerly latitudes. We have not as yet discussed the magnitude of this difference. Some of us think it is about 10 percent greater than the gamma dose that would be produced based on computations from the older mechanisms.

Representative HOLIFIELD. But the measurements have been made on the actual fallout in the gamma field recently.

Mr. EISENBUD. One of the difficulties, sir, is that the gamma doses from fallout are so small that they can't be measured with instruments. These changes due to fallout are so small that the changes are completely masked by natural radioactivity. Therefore, what we have to do is to collect the fallout as dust and then compute what the gamma dose would be if it were spread out.

Representative HOLIFIELD. So to make the record clear the fact that there is a shorter residence time in the stratosphere and a quicker precipitation to the earth of the debris does not necessarily mean that you are raising appreciably the gamma level on the earth's surface from these tests.

Mr. EISENBUD. This seems to be our conclusion at the present time.

Representative HOLIFIELD. You are saying that it has decayed enough, in other words, in the time period that it takes to come down that it is less than the background radiation, and therefore difficult to measure. Have I stated it clearly or incorrectly?

Mr. EISENBUD. I would like to say that this at the moment must remain an unresolved question, although we perhaps can set some limits. I find that most of us believe the increased gamma dose to be of the order of 10 percent, which one might say is small. This is from past tests. The possibility exists, though, that for the individual Russian test series, because they were conducted in the Arctic, the gamma dose delivered to populations in northern latitudes may actually have been several times what it would have been had the same test series been conducted in more southerly latitudes. This is to say that the Castle test, for example, produced much less gamma radiation than the Russian tests of last October.

I think I may have overlooked some points that should have been included.

Representative HOLIFIELD. We will get to them as we go through the discussion. The testimony yesterday indicated a difference of opinion on whether the greater fallout at certain times is the result of seasonal factors or is primarily a matter of the timing of shots. I think Dr. Machta took the former position of the seasonal factor influence and Dr. Martell took the position that it might have more to do with the timing of shots. May we have a discussion on that? Dr. Machta, you might lead off.

Dr. MACHTA. The reasons for objecting to Dr. Martell's views are severalfold. One was mentioned yesterday, and I will repeat it again. This is the fact that in the spring of 1955 there was a maximum in strontium 90 deposition taking place. However, to the best of my knowledge there was no stratospheric injection in the autumn of 1954, while there have been Russian stratospheric injections in the autumn of 1955, 1956, 1957, and 1958. This suggests to me that we are dealing with an atmospheric phenomenon rather than a previous fall atomic test. Of course, there is the possibility we missed the test in the autumn of 1954.

Representative HOLIFIELD. Dr. Martell?

Dr. MARTELL. I would like to mention that if one looks at the istope ratio in rains, the large increases in strontium 90 associated with Russian tests, normalized to the size of the test, show very large effects related to the test origin which mask whatever seasonal effects may occur. A seasonal effect of the order of magnitude observed in the spring of 1955 peak would indicate an increase of a factor of two in concentration in the spring compared to much larger factors observed in subsequent years. When you associate that small factor of two with the major U.S. test of the previous year, it appears to me that we may not be dealing with a very important seasonal effect.

There is a remaining possibility. The isotope ratio indicates that the fall 1954 tests of the Russians, though small, made significant contribution in the spring of 1955. This is quite an open question. If you believe the isotope ratio data that says a typical Russian test causes of the order of 40 to 50 times the intensity of fallout during the following year than do the Castle tests on a per megaton basis, then it makes it sensible to say that the small weapons tests in the fall of 1954 did contribute a significant percentage of the spring 1954 peak.

I think the vast differences in the Russian test and U.S. test on a rate and concentration basis are quite clearly indicated by the isotope data, and we have not paid enough attention to it in our analysis of past data.

Representative HOLIFIELD. Dr. Machta?

Dr. MACHTA. The analysis which Dr. Martell makes assumes that all of the short-lived fission products are derived from stratospheric debris several months old, when in fact during the past few weeks prior to one of the fallout measurements there was tropospheric fallout. He essentially assumes that tropospheric fallout is entirely negligible insofar as its contribution to short-lived fission products is concerned. We know from data in 1952 and 1951, during a period in which there was no stratospheric drip, that there was in fact a very

large amount of tropospheric fallout. This is being neglected in Dr. Martell's theory, and for this reason I suspect some of the results which he may be obtaining.

Dr. MARTELL. I would like to comment on that.

The important conclusions with respect to the fractions of strontium 90 that come from Russian tests or from U.S. tests are quite independent of whether you say the barium 140 and the strontium 89, the short-lived activities, are tropospheric or stratospheric. The possibility that short-lived activities are derived from the stratosphere from the Russian tests, as a consequence of rapid fallout of Russian tests, is clear in our data for 1958. There were very limited small weapons tests in 1958 that would affect these results. My earlier analysis for earlier years is based on data from Harwell, England. At these distances the Nevada tests do not seeem to be important and for the same reasons in the United States in 1958 small weapons from Russia do not seem to be very important.

The conclusion of whether or not the short-lived activity is stratospheric of tropospheric does not change the relative contribution of strontium 90 and the relative concentration of strontium 90 that I estimate for Russian versus equatorial tests.

Representative HOLIFIELD. I think that the base has been stated pretty thoroughly by the two proponents. Is there any comment on that from others present?

Mr. EISENBUD. I would like first of all to emphasize again that we all agree that this increased fallout in the spring months does occur. That is what is important from the point of view of how much strontium 90 we are exposed to. As is so often true, I think everybody is right. The fact of the matter is that the Russian tests in October injected so much into the upper atmosphere that the total stratospheric inventory was almost tripled. If for no other reason at all, one would expect that the fallout would begin to increase and perhaps double or triple simply because of the amount of additional material in the stratosphere.

I would like to refer again to Mr. Holland's chart which is derived from data we have collected in New York since early 1954.

It shows the general accumulation of strontium 90 in the New York area. I call your attention in particular to these little bumps. Here is the spring of 1955. That is the first big one that we saw. We saw another one at the beginning of 1956. Then a great big one in 1957. This is a very large one. Then another one in 1958. Now in March of 1959—I will just put this in by pencil—you can see there has been another big bump. Dr. Martell says this bump is due to the Russian debris of October. I think some of it undoubtedly is. On the other hand, the fact that these bumps have occurred between February and May of every year since we started to collect indicates that perhaps there is a seasonal factor, too.

The question is, how do you separate the one from the other, and one says we can't. We just don't know enough about it.

Representative HOLIFIELD. Dr. Martell.

Dr. MARTELL. I did not have time in my verbal testimony yesterday to develop the idea of what kind of seasonal effect we may be dealing with, but my formal testimony does. It appears that we have a very remarkable shift every summer, so that rather than getting

a change in rate of mixing of stratospheric air down into the lower atmosphere, we seem to have a change in the source of the stratospheric air, as though in the first 6 months of each year we are receiving air from the lower stratosphere at high altitudes and thus we see Soviet test debris during the first half of the year overwhelmed by the most recent Soviet production.

Then we see this remarkable change, a drop of a factor of four or five in strontium 90 concentration in rains and in air occurring every summer in July or August. In addition to this sharp change in concentration, we are suddenly seeing, on the basis of isotope ratios, equatorial debris from either British or U.S. tests. So it is as though we close the door on Arctic stratosphere air, and open it to stratospheric air from the equatorial regions. One can make this sort of a model consistent with the Brewer circulation system that Dr. Machta describes, but it shifts the emphasis or the path somewhat at various times of the year. It gives you a very sharp difference in the origin of the debris during the two halves of the year.

Representative HOLIFIELD. Could I as a layman say that we are agreed that in the spring of the year we would have this phenomenon of increased fallout, and that weather conditions do have something to do with it? That is, the turbulence and the gaps in the tropopause have something to do with it? As to why this occurs, there is a difference of opinion among scientists. But the important point to us laymen is that we get it in the spring along with the roses and the violets.

Dr. LIBBY. I think, Mr. Holifield, this spring is really different. These are the two curves (see p. 892), this spring and last spring. It is true that they are not the same city, but the Pittsburgh data ought to be pretty similar to the Washingon, D.C. This is Washingon, D.C., this year. So though I agree with Mr. Eisenbud in his generalization that there is always a spring rise, this spring is higher. I don't think there is any doubt about it.

Representative HOLIFIELD. This spring is higher in Washington, D.C., than it was in Pittsburgh.

Dr. LIBBY. Than it was in Pittsburgh last year.

Representative HOLIFIELD. Is the Pittsburgh level a year ago?

Dr. LIBBY. That is the 1958 Pittsburgh level. I had to use 1959 Pittsburgh, because we did not have any 1958 Washington data. I may say that the 1959 Pittsburgh data as they are coming in seem to be falling more on this curve than on this curve. So though Mr. Eisenbud is certainly right, there is always a spring rise, this spring is hotter than any others.

Mr. EISENBUD. I would agree with that.

Representative HOLIFIELD. And there is a strong indication that this might be traced to the Russian tests in October.

Dr. LIBBY. It is the Russian October series.

Dr. SHELTON. That is the point.

Representative HOLIFIELD. So there is no contention on the part of either of the two proponents that there is a connection between the tests and the season. The contention is in the difference of the degree which you apportion to either the seasonal influence or the timing of the test.

Dr. MACHTA. Yes.

Dr. MARTELL. Yes.

Representative HOLIFIELD. I think that is pretty well covered now.

Chairman ANDERSON. I just want to say, Mr. Holifield, that is a fine accomplishment because every head was nodding in the same direction.

Representative HOLIFIELD. If I attempt to summarize this in layman's terms, it is only to be sure that I know what you are talking about. I figure if I can understand it, anybody who reads this record will be able to understand it.

Mr. HOLLAND. Mr. Chairman——

Representative HOLIFIELD. I hope this is not a note of difference.

Mr. HOLLAND. No, sir; on the contrary, to confirm what Dr. Libby said at the end of February in Pittsburgh the level was 2.99 in 1959 as compared with about 1 in 1958. So although we are lagging a little bit behind in the analysis of the Pittsburgh data, compared to Dr. Libby's Washington data, the levels are rising on a very comparable slope at Pittsburgh.

Chairman ANDERSON. Would it be safe to say that there is not a city in the United States getting a greater amount of fallout?

Mr. HOLLAND. I think this would be safe to say. I had one other comment on this. Depending on which of these two hypotheses is correct, the fallout next spring would be different if there are no further tests. If it is due to Russian fall tests, we would not see an appreciable spring peak next year. But if it is simply a meteorological seasonal effect, then we will have another spring peak next year. There are different implications in the two hypotheses.

Representative HOLIFIELD. Which means that we have to have a little longer time period to be sure about statistical estimates in this area.

Mr. HOLLAND. Yes, sir.

Representative DURHAM. If you don't have any further tests, we will still get an increase of radiation fallout.

Mr. HOLLAND. Yes, sir. I only meant to say that the increase would not have the same seasonal pattern, but certainly there would still be a predictable increase.

Representative DURHAM. We will just have to wait and see?

Mr. HOLLAND. Yes.

Representative HOLIFIELD. The testimony before the committee has been that it will be higher next year regardless of the fact that we have tests or not. Is that not right?

Mr. HOLLAND. The total accumulation will be considerably higher next year.

Representative HOLIFIELD. But not the rate of fallout?

Mr. HOLLAND. That is correct. But the question is whether it will come down uniformly over the year or whether the rate of fallout will drop off during the fall and then pick up again next spring even in the absence of any tests during the year.

Representative HOLIFIELD. That brings us to the next question on the distribution of fallout. Do all countries in the Northern Hemisphere at the same latitude get higher fallout? Why is the United States receiving the heaviest fallout? Who do you wish to speak on that subject?

Dr. LIBBY. There is one obvious reason. We have the Nevada test site, and we get some from that. Perhaps you did not have reference

to that. When you are close to a test site, you do get some from the test site. We think that has contributed between 10 to 15 millicuries per square mile in the United States.

Representative HOLIFIELD. Let us take this in two sections. Let us take what we might call the local continental fallout from Nevada test as No. 1, and No. 2, let us consider it from the standpoint of the stratosphere.

Dr. LIBBY. I don't know of any evidence except for local differences in rainfall. Of course, you know, Mr. Chairman, that there are differences in rainfall. If you go to the Imperial Valley in California, the vegetables there have practically no strontium 90 in them. It is irrigation water and this has all been cleansed of strontium 90 by the action of the soil over which it flowed. So the rainfall is a factor which is very important. That could cause places in the same latitude to have different total fallout. We see that in our actual data.

Representative HOLIFIELD. But generally speaking, the high latitudes in the Northern Hemisphere regardless of which country will have approximately the same fallout, conceding the difference between rainfall areas and dry areas.

Dr. SHELTON. Yes, sir. The United States should not be singled out. The situation is comparable in Europe except for our proximity to the Nevada test site, which has made a small contribution to the U.S. values. It is typical of the north temperate latitudes.

Representative HOLIFIELD. Is there any comment on that or any disagreement on that point?

Mr. HOLLAND. Sir, I believe that the differences might be minor within the latitude zone. However, I think it is common in meteorology to find differences in all the elements from one longitude to another. If you look at an average chart of wind, you find at one longitude you may have a northwesterly wind at latitude 45, for instance, and at another longitude you might have a westerly or southwesterly average wind. With this there would be some regions in which there would be preferentially downward motion in the lower atmosphere, and other regions where it might be preferentially upward. So I think some systematic variation around a latitude zone would be expected. We don't have enough fallout data to correlate the variations of observed fallout with the variations of other climatic elements as yet.

Representative HOLIFIELD. There is general agreement on that statement. The panel nods signify "Yes" for the record.

This brings us to the subject of hot spots or hot areas. What factors cause their formation and what deviations from the averages can we expect? Also, what are the general sizes of these so-called hot-spot areas and the reasons that can be ascribed to them?

Mr. EISENBUD. I would be willing to discuss that, Mr. Holifield, if we could first have a definition of what a hot spot is. I think different people mean different things when they use the word.

Representative HOLIFIELD. You set your own definition on it.

Mr. EISENBUD. Let us first take an area the size of a county or a large city. We find from our soil analysis that the big deviations from the mean are on the low side. This is what one would expect. We know that the total fallout in any given area is related to the amount

of rainfall in the area. As Dr. Libby has noted, if we go to a desert, we find that the fallout in that area may be a very small fraction of the mean for the whole United States. When I say small fraction, I mean something of the order of 5 percent or less than that, perhaps 2 percent. It would be one-fiftieth of the average.

A more important question concerns the locations whose levels are larger than the mean. Here we have no evidence that in the United States the soil—I am sorry, we do have evidence now with our 50th State—in continental United States we have no evidence that our soils in large areas would be greater than, say, twice the mean. The one exception, sir, is in Hawaii, which I must agree is now in the Union. There we did find in a several-hundred-inch-rainfall region a higher result of some 79 millicuries per square mile, which would be greater than twice the mean.

I would say for large areas a factor of two would define the other limit. Others may disagree with that, but this is my personal opinion. I hasten to add that there may be other factors which could produce a greater variation in the strontium 90 content of foods from the region, and this I think is a subject which will come up later on in the symposium. It is my own personal opinion that factors related to the chemical composition of soil and the feeding habits of stock animals would have a much larger factor of influence on the strontium 90 content of foods produced than would differences in fallout per se. My colleagues may disagree with me.

Representative HOLIFIELD. We will give them an opportunity right now to disagree with you if they do.

Dr. LIBBY. I think I agree with Mr. Eisenbud. Don't you, Dr. Langham?

Dr. LANGHAM. I surely do.

Dr. LIBBY. I think these other factors would predominate over the rainfall effects. I think at the same time we ought to realize that we have not as many data to settle this point as one might want. We have been trying to cover the whole world except the Soviet Union in our soil sampling program, and it is a pretty big job. So if we look at our maps, the points are pretty far apart, I must say, but they seem to fit together and make sense if you correct for variation in rainfall.

Dr. MACHTA. Using the fallout data in October of 1958 and determining the amount of fallout per inch of rain, we have attempted to compute the fallout which would have occurred at places in between the observed stations. The 275 such points over the continental United States have been so computed, and we find that there is no place that contains appreciably more fallout than the places in which we have actually sampled. There were exceptions probably on the side of mountains where the rain water would actually roll down the mountains. It would not be significant in terms of agriculture. As far as we can see from this study of 275 stations, we have sampled more or less the "hottest" areas, except for the area immediately around the proving grounds.

Representative HOLIFIELD. In your opinion, does the 275 stations give us a very accurate picture?

Dr. MACHTA. I would rather put it that there is no evidence to suggest that there are other large areas, which because of higher rainfall, have much greater fallout.

Dr. LIBBY. Wouldn't you at the same time, though, Dr. Machta, point out that our knowledge of the fallout over the ocean is rather weak?

Dr. MACHTA. Yes.

Representative HOLIFIELD. In this case we can be thankful that six-sevenths of the earth's surface is in the ocean.

Now let us return to the problem of faster fallout. What is the significance of the fact that radioactive debris is coming out of the stratosphere at a faster rate than previously estimated? What has been the impact of the Russian test series on our forecasts of future deposits? There has been some discussion on this already but I think for the record we might make this a fairly complete discussion at this time.

Mr. EISENBUD. I would personally rest on the conclusions of the U.N. report. This was a study involving scientists of 15 nations. It took 2½ years to draft and it considered the residence time very thoroughly, and concluded that if there was a difference, the fact that the fallout rate was faster would simply indicate that the inventory in the stratosphere is less, and, therefore, the potential hazard is reduced correspondingly.

Representative HOLIFIELD. The potential all-over hazard?

Mr. EISENBUD. Yes, sir. The hazard from strontium 90 and cesium 137 and other long-lived activities.

Representative HOLIFIELD. Dr. Shelton?

Dr. SHELTON. I think I should say that the general conclusion of lowering the stratospheric inventory as a consequence of the faster trip-out rate—in this analogy we have been using a bank—what we have been looking at is the number of checks coming out on the ground. From that we have been estimating the bank account, which is the stratosphere. We have said if the checks come out real fast, the amount of reserve in the bank is small. We don't have to do that approximation any more.

There have been a number of bank examiners now go into the bank, not as bank robbers but as bank examiners. We have been there and we have essentially audited the account. We don't have to guess as we did in 1957. We have been there, and we do now confirm the conclusion of the U.N. that there is less in the bank than we had been presupposing when we had the long residence time. I think this analogy sort of tells you that the U.N. came to the right conclusion by a mechanism of extrapolating to say what was in the bank, and now we have in a legal way gone into the bank as examiners and said that is correct.

I would agree with the U.N. conclusion as to what was in the bank.

Representative HOLIFIELD. Then to carry the analogy further, a check with insufficient funds is not negotiable.

Dr. SHELTON. That is right.

Representative HOLIFIELD. Is there any difference on that?

Dr. MACHTA. As a representative of the World Meteorological Organization to the U.N. Scientific Committee I took exception to what the U.N. had done, and let me state why.

Representative HOLIFIELD. We may find we can send the check out after all.

Dr. MACHTA. The U.N. properly obtained the amount which was deposited on the ground. Then they accepted the 5-year residence time to determine the stratospheric content. But it turns out the only way you can determine the 5-year residence time is by having someone previously guess how much was in the stratosphere. This is going around in circles—guess at the stratosphere, find out what the residence time is from deposition, and forget about the fact that you never knew what was in the stratosphere in the first place, take the deposition, use the 5-year time, and go back into the stratosphere. This is a circular argument which I contend is wrong.

Now as Dr. Shelton says, we don't have to go into this circle and we are much better off.

Dr. SHELTON. But we would conclude that there was less in the bank than people had been presupposing on a 5- or 10-year basis.

Dr. MACHTA. Yes.

Dr. SHELTON. The result was that we both went the same way, having measured it or having predicted it.

Mr. HOLLAND. I think there would be little disagreement on this if we did not attempt to look at the stratospheric residence time or the relative fallout rate as an isolated thing. The faster fallout has several consequences. It results in possibly less complete global distribution before material is deposited. It results in less decay before the material is deposited. These result in higher radiation doses. It depends on what your starting point is. If you make an assumption regarding the inventory and you say so much has been put up, then the faster it comes down, I think there is no question, and everyone would agree that the higher would be the radiation doses to people. However, if you make the assumption that you know at what rate the actual radioactivity is depositing on the ground, then the faster it comes down, the more quickly the reservoir will be depleted, and the less will be the total dose. It depends entirely on what your starting assumptions are as to whether you conclude that a faster fallout or a shorter residence time is good or bad. You can't assign a value to it at all by itself.

Representative HOLIFIELD. Could I say then that continued testing would continue to increase the bank deposit that we have been talking about—the deposit in the stratosphere—of radioactive material, and therefore more checks could be drawn on it into a further time period than if it stopped at the present time? Your answer to that is "Yes," I believe.

Mr. HOLLAND. Yes, sir. Now our interpretation of the checks has to be one that implies some harm coming. If the checks are being spent on liquor, for instance, the faster you spend it, the drunker you will get, or something like that.

Representative HOLIFIELD. We won't go into the use of the money because that would be complicated. Could I ask if the HASP and the Ashcan data are reliable enough to draw these conclusions or to support these conclusions?

Dr. SHELTON. I would rather speak about the HASP data. I am intimately familiar with the Ashcan data, too. Let me speak of the HASP and I would like perhaps Dr. Machta to say a few words about the Ashcan.

I think within the uncertainties of the two programs they are in agreement. Typically the Ashcan inventory has been less in the stratosphere than our HASP program has shown. In other words, if there is uncertainty in the two programs, the HASP program indicates a higher amount of material in the stratosphere than typically the Ashcan program has shown. I think the HASP results are good enough for the inventory. If they were any more accurate I still don't know what anybody would do with the data.

There is always the possibility, and I would never put my two feet firmly on the floor and say this is the answer, because I think there can be something funny going on. To the extent that there can be odd things happening in the stratosphere, such as a streaming of debris injected in the equatorial region to very high altitudes where nobody is sampling and streaming back in at the poles—except for something that is going on that is beyond our measurement capability—I think the HASP data is good within 25 percent overall. In other words, if I gave you an inventory of 12 megatons in the mid-1958 series—I said yesterday it was like 12 megatons—I think it could be as high as 15 and as low as 9. But it is like 12. I think the rest of the story is the Ashcan data.

Representative DURHAM. Doctor, since all of these programs are new and something we have never done before, has there been any thought given to the fact that some of this might have been in the stratosphere prior to that? What is the opinion of the scientists as to that?

Dr. SHELTON. That there was fission debris in the stratosphere prior to nuclear testing.

Representative DURHAM. Yes.

Dr. SHELTON. Somebody could say, for instance, that strontium 90 is a short-lived isotope really. We are talking about something that has a lifetime of 28 years in the several billion years of the life of the earth, and it is insignificant. There might have been strontium 90 away back eons and eons ago. It did not live. In 280 years it died to nothing. The only radioactivity on the earth today—natural radiation activity on the earth—stems from long-lived materials. Uranium and thorium have lifetimes of 10 to the 9th or 10 to the 10th years. All the natural isotopes stem from those long-lived materials. There are short-lived isotopes in the decay chains. So there just could not have been any natural fission debris in the stratosphere. There can be radioactive particles in the atmosphere, such as carbon 14 being created in an equilibrium way by the cosmic rays. There just can't have been any of the short-lived fission products.

Representative DURHAM. Is that pretty well in agreement?

Dr. LIBBY. I think the best evidence, Mr. Durham, is that pre-atomic milk and food samples do not have strontium 90 in them. If it were in the stratosphere it would be coming down and it would get into the cow's milk and we would see it. Pre-atomic food does not have strontium 90 in it. So I think that just about settles it. Of course, all the theory, as Dr. Shelton has indicated, says it should not be there, but we have measured these samples and they do not have strontium 90 in them.

Representative DURHAM. The reason I asked the question is because the behavior of the stratosphere and the troposphere and all

the other fields might have resulted in it being deposited. I was thinking of the fact that after all we have the sun and certainly we could have thermonuclear heat and there might be a possibility that we didn't discover this. I am not arguing with you scientists. I am just a layman.

Representative HOLIFIELD. If you get away from the elements such as lithium, uranium, and get into the cosmic ray belt of radiation, that seems to be independent of any earth element. There could be something in relation to a higher intensity of ions going by in cosmic bombardment of the earth, could there not? That is speculation, I suppose.

Let us go to the next point.

Representative DURHAM. We are more or less convicting our own selves of most of it being manmade.

Dr. LIBBY. It is manmade.

Representative HOLIFIELD. I would like to hear Mr. Holland on the Ashcan.

Mr. HOLLAND. I would say that our estimates of the stratospheric inventory of strontium 90 by means of Ashcan measurements are considerably more uncertain than those that we get by combining Ashcan data with HASP data, which was the basis of Dr. Shelton's estimate. In other words, resting the estimate on the Ashcan data alone makes it more uncertain. Such attempts have been made to make an independent estimate using Ashchan data alone and, as I mentioned yesterday, an estimate of the average for the first half of 1958 of 6 megatons was obtained as a lower limit. By juggling the filter efficiency factors and the amount of debris that you imagine in the parts of the world where you don't have samples, this can easily be raised to a number equal to that obtained in the HASP program of 10 to 12 megatons. So I would say that basically the data are not at all in disagreement, but that one does not get as good an estimate by using the Ashcan data alone.

Representative HOLIFIELD. Is there general consensus of opinion on the part of the panel to the statements of the two gentlemen?

Mr. HOLLAND. I think I should add something to this; because of their uncertainy if you do not combine them with HASP data, or even in combination with the HASP data, the uncertainties of interpretation of the Ashcan part of the sampling permits a wider range of estimates to be made. For instance, if you think that the Ashcan filter efficiency is extremely low at high altitude, it would be possible to obtain inventories which would be much larger than those obtained by the HASP program. This would be essentially not trusting the Ashcan data, and not believing whatever experimental evidence we do have on its filter efficiency.

Representative HOLIFIELD. Again I propound the question, Is there general agreement to the positions that have been stated, including the uncertainty of the difference in calculation?

Dr. SHELTON. How do you feel, Dr. Machta? You have looked at both.

Dr. MACHTA. Not only do I agree, but there is a third piece of information which likewise supports it, and this is the integration of the manmade carbon 14 in the atmosphere which gives numbers al-

most identical to the numbers quoted by Dr. Shelton. So there are three pieces of evidence which all give the same results.

Representative HOLIFIELD. We have not considered the second part of the question. What has been the impact of the Russian series on our forecasts of future deposits?

Mr. EISENBUD. Mr. Chairman, this has been considered by perhaps half a dozen people in this room, most of whom are at this table. These findings are being consolidated into a statement which will be submitted to the committee at tomorrow afternoon's seminar if we can defer it until that time.

Representative HOLIFIELD. We will defer it until that time. We get to the fission yield estimates. With regard to the new figures released yesterday on fission yield totals for the United States, United Kingdom, and Russian weapons testing, what is the basis on which distribution of debris resulting from these detonations is estimated?

Dr. LIBBY. This will be treated tomorrow afternoon in the seminar more completely. We will spread it out over the Northern Hemisphere, keeping it entirely in the Northern Hemisphere. Our present evidence is that the Russian debris—I am speaking of the Russian October series in the polar regions—will not reach into the Southern Hemisphere to any appreciable degree. Maybe some will, but I showed you the curves of Dr. Lockhart yesterday, which indicate very strongly that it does not seem to want to cross the Equator. So that will come down in the Northern Hemisphere.

In our ignorance, we don't quite know whether it is going to fit the exact profile of the soil deposits or not, but something like this will probably be the shape, with a peak in the middle latitudes which it will have. For the remainder of the material in the stratosphere, we are going to put that into the two hemispheres, and the ratio of deposits in the two hemispheres we will discuss tomorrow. The total of the 30 megatons in the stratosphere, we distribute between the two hemispheres in a ratio varying between 5 to 2 and 5 to 1. We will go into it in more detail tomorrow afternoon.

Representative HOLIFIELD. The basis of these estimates, of course, is from the various sampling facilities which we have throughout the world.

Dr. LIBBY. That is right.

Representative HOLIFIELD. As well as the United States.

Representative VAN ZANDT. Mr. Chairman, I would like to ask of Dr. Libby about the adequacy of models and sampling systems.

Dr. LIBBY. Our soil sampling, rain sampling?

Representative VAN ZANDT. Yes.

Dr. LIBBY. I think it is pretty good, Mr. Van Zandt. We are getting more stations all the time, and we are really fortunate to have Dr. Alexander to take these soil samples. He covers the world pretty well. It is a big job. It is a very delicate operation taking these soil samples so that they will be meaningful. For example, there are always such questions whether the sample is taken from under a tree or whether it is taken on a slope where the soil is moving. He has developed a great deal of skill in picking out the right soil samples to take. So I think the soil sampling, though it can be increased somewhat, ought to still be done in Dr. Alexander's way, so that we

get good samples. I think it is adequate. I would like to see more, frankly, but it is a lot better than we have had in past years.

Regarding the rain pots where we put out wash tubs to collect rain, we have a pretty good empire now. I think this could be increased somewhat with profit. We will try to do this. In regard to the sampling of food and of human bone, I think the food sampling could be increased with real profit. As Dr. Dunham has said yesterday, though, the measurement of these samples is rather difficult, and we get a backlog rather quickly. If we take in too many samples, we get a bottleneck in our measuring and then we must choose which has the highest priority.

We are improving that. More and more people are measuring. More and more laboratories have learned to make these measurements. It will be particularly helpful when the other countries in the world begin to make more measurements. This is happening now, and as the UN collects data from the various countries, we are going to have an increasing amount of information added to what the United States is collecting. So I think in total it is pretty fair. It is not perfect. It is pretty fair.

Representative VAN ZANDT. Then I understand you would advocate an expansion of the sampling system.

Dr. LIBBY. I would advocate a modest expansion in some areas.

Representative VAN ZANDT. What about the research needed to improve the analytical methods used in these programs?

Dr. LIBBY. This can be done. I think the greatest need is to get more people who know how to use the methods we have now. Of course, if we had a method where all you had to do was to hold a geiger counter up to a piece of cheese and get the reading, that would be wonderful. Nowadays it takes a couple of weeks before we get the reading, and it is pretty slow. There is room for improvement but I don't know exactly how to do it. We intercalibrate. We exchange samples between various countries and laboratories.

Representative VAN ZANDT. What comments would you have, Doctor, on the stratospheric sampling? Do you think our efforts are adequate?

Dr. LIBBY. I think it will improve rapidly. We have a beginning. I think the Ashcan data are very weak now. I think we will find out what is wrong and we will correct that. We have the technique of getting the balloons up there and getting the samples, and that is the heart of the thing. If we could just analyze them better, we would be in. The HASP data are beautiful data. The only difficulty I have is that there may not be enough of them in certain ways. But the principle is fine.

Representative VAN ZANDT. What about our program of sampling when new countries enter the testing field?

Dr. LIBBY. Our network ought to take care of it. We might have to expand it in certain areas, but it will take care of it.

Representative VAN ZANDT. Doctor, you are leaving the Commission on June 30, is that correct?

Dr. LIBBY. That is right, Mr. Van Zandt.

Representative VAN ZANDT. You have been spearheading this effort as far as the Commission is concerned, is that right?

Dr. LIBBY. I have had a fair amount to do with it.

Representative VAN ZANDT. This has been your responsibility, we will say, as a member of the Atomic Energy Commission?

Dr. LIBBY. I spend more time than most of the Commissioners on it, yes, sir.

Representative VAN ZANDT. Do you anticipate after you have left the Commission and taken up your new position on the west coast that you might still continue in this field probably as a consultant?

Dr. LIBBY. It is so interesting scientifically that I think probably I will in one way or another. It is very interesting to study the way the rain brings down this debris. It is very interesting scientifically.

Representative VAN ZANDT. Doctor, looking into the future, based on the fact that our knowledge of sampling expands annually, is Congress providing sufficient funds to meet the needed expansion of facilities and personnel?

Dr. LIBBY. I believe that is true. We have never had a feeling of being pinched for money in the fallout program. I should not say never. Not in the last 4 or 5 years. I would not be as familiar with the earlier years. That is essentially true, Mr. Van Zandt. You never can say that if you had an infinite amount of money you would not have gained something. I don't think money is the limiting thing. The limiting thing is the number of people who can analyze these samples and get good data. This is really the bottleneck.

Representative VAN ZANDT. In other words, you are saying, as you understand it and see it, this is a major effort.

Dr. LIBBY. This is a major effort.

Representative VAN ZANDT. And it has the full support of the Government as well as the Congress.

Dr. LIBBY. Yes, sir.

Representative HOLIFIELD. Mr. Eisenbud.

Mr. EISENBUD. I would like to add one point which was touched on briefly by Dr. Libby. Our requirements are related as much to the quality of samples as to their quantity. I think our milk data illustrate this very well. Several years ago we went to the Department of Agriculture and asked them to recommend a few milksheds which in their opinion based on their knowledge of fallout, soil chemistry, and meteorology, would span the levels of strontium 90 in milk in the United States. They came up with four milksheds. That was several years ago. To date many additional milksheds have been added to the network but to date, to my knowledge, no one has come up with any values which are either higher or lower than the values within the range of the four milksheds recommended to us by the Department of Agriculture. I think this is very significant.

Representative HOLIFIELD. On the basis of the sampling that we are doing in the milksheds, we can be assured—the American people can be assured—that there is an adequate testing of this to furnish scientific data on which we can base our estimates of damage or no damage?

Mr. EISENBUD. Yes, sir.

Representative HOLIFIELD. I believe that ends the panel discussion.

Representative VAN ZANDT. Mr. Chairman, before we conclude this discussion, I wonder if we could take the Minnesota wheat incident and explain how that was handled for the record. In other words, to support the fact that information was at hand and you had to immediately answer to meet the situation.

Dr. LIBBY. We have analyses of the Minnesota wheat which were obtained from samples sent to us by Dr. Vischer of the University of Minnesota, and some samples of our own. These analyses indicated values such as Dr. Dunham said yesterday were high and vacillated from year to year. That is, in one year they would be high; the next year they would be low; the next year they would be high, and so on. This has led us to believe in conjunction with other information on certain of the milksheds Mr. Eisenbud referred to, and certain data furnished to the United Nations Scientific Committee on Atomic Radiation, particularly by the Japanese, that we have been paying too little attention to the leaf pickup.

It is my personal belief that the high values in the Minnesota wheat were due to direct pickup on the leaves of the wheat rather than through the roots. In other words, it is a temporary thing depending on the rate of fallout and the weather conditions.

It is difficult to know right at this time just what percentage of the pickup in Minnesota wheat was from the leaf and what from the root, but it seems to me likely that the major part of it was leaf pickup. It was one of this kind of concentration and fallout in the particular growing period which led to this.

Further measurements, of course—and we will make these measurements and follow this—will elucidate this because we ought to see the parallel, if it is leaf pickup, the amount in the rainfall or something like the amount in the rainfall. We ought to see that. We ought to see this Russian October fallout in the wheat and so on. We will follow that.

Representative VAN ZANDT. Thank you.

Representative HOLIFIELD. Thank you, gentlemen. I note that we have had remarks from all of the panel except Mr. Hollister, who was on our staff 2 years ago, and Dr. Langham, who will appear in the next few minutes. I could not let this occasion go by without expressing the committee's appreciation not only to this panel, but also to the work which Mr. Hal Hollister did in 1957 as a member of our staff. We have his associate, Dr. Paul Tompkins, from the Naval Radiological Laboratory, with us this year, and he is carrying on for the double job that you had last year. I will confess it is easier for the committee and the staff, too, this year, because of the groundwork that was laid in 1957. Thank you, gentlemen, very much.

Mr. HOLLISTER. Thank you very much, Mr. Holifield.

Representative HOLIFIELD. Our next subject is "Summary of New Data on Uptake in Milk, Food, and Human Bone," and we have asked Dr. Wright Langham and Dr. Conrad Straub to appear before the committee to discuss this subject.

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